DOCUMENT RESUME

ED 246 217	CE 039 202
TITLE	Electronic Principles II, 7-6. Military Curriculum Materials for Vocational and Technical Education.
INSTITUTION	Air Force Training Command, Keesler AFB, Miss.; Ohio State Univ., Columbus. National Center for Research in Vocational Education.
SPONS AGENCY	Department of Education, Washington, DC.
PUB DATE	75
NOTE	316p.; Portions of Plan of Instruction may be marginally legible due to poor print quality. For related documents, see CE 039 201-210.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF01/PC13 Plus Postage.
DESCRIPTORS	Behavioral Objectives; Course Content; Course Descriptions; *Electric Circuits; *Electric Motors; *Electronics; Engines; Individualized Instruction; Learning Activities; Learning Modules; *Magnets; Pacing; Postsecondary Education; Programed Instructional Materials; Secondary Education; *Technical Education
IDENTIFIERS	Military Curriculum Project

ABSTRACT

This second of 10 blocks of student and teacher materials for a secondary/postsecondary level course in electronic principles comprises one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. A prerequisite is the previous block. This block on AC circuits contains nine modules covering 44 hours of instruction on AC composition and frequency spectrum (7 hours); capacitors and capacitive reactance (6), magnetism (4), inductors and inductive reactance (5), transformers (4), relays (3), microphones and speakers (3), meter movements and circuits (5), and motors and generators (7). Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text; nine guidance packages containing objectives, assignments, and review exercises for each module; and two programmed texts. A digest of the modules in the block is provided for students who need only to review the material. Designed for self- or group-paced instruction, the material can be adapted for individualized instruction. Additional print and audiovisual materials are recommended but not provided. (YLB)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

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- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
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FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

- Agriculture
- Aviation
- Building & Construction Trades
- Clerical Occupations
- Communications
- Drafting
- Electronics
- Engine Mechanics
- Food Service
- Health
- Heating & Air Conditioning
- Machine Shop
- Management & Supervision
- Meteorology & Navigation
- Photography
- Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

ELECTRONIC PRINCIPLES II

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ELECTRONIC PRINCIPLES II

Classroom Course

Developed by:

United States Air Force

Development and Review Dates:

July 1974 through November 1975

D.O.T. No.:

003.081

Occupational Area:

Electronics

Target Audiences:

Grades 11-adult

Print Pages:

303

Cost:

$6.25

Availability:

Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials: Lesson Plans:	Programmed Text:	Student Workbook:	Handouts:	Text Materials:	Audio-Visuals:	Instructional Design: Performance Objectives:	Tests:	Review Exercises:	Additional Materials Required:	Type of Instruction: Group Instruction:	Individualized:	
			No. of pages										
Block II – *AC Circuits*													
Module 11 – AC Computation and Frequency Spectrum		●	22		●	★	●	★	●				
Module 12 – Capacitors and Capacitive Reactance			12		●	★	●	★	●		●	●	
Module 13 – Magnetism			6		●	★	●	★	●		●	●	
Module 14 – Inductors and Inductive Reactance			10		●	★	●	★	●		●	●	
Module 15 – Transformers		●	14		●	★	●	★	●		●	●	
Module 16 – Relays			10		●	★	●	★	●		●	●	
Module 17 – Microphones and Speakers			4		●	★	●	★	●		●	●	
Module 18 – Meter Movements and Circuits			6		●	★	●	★	●		●	●	
Module 19 – Motors and Generators			8		●	★	●	★	●		●	●	

★ Materials are recommended but not provided.

Expires July 1, 1978

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Course Description:

This block is the second of ten blocks providing training in electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles and troubleshooting basic circuits. A prerequisite to this block is Block I—*DC Circuits*. Block II—*AC Circuits* contains nine modules covering 44 hours of instruction on frequency spectrum, capacitors, magnetism, reactance, transformers, relays, and electromechanical devices. The module topics and respective hours follow:

Module 11	—	AC Composition and Frequency Spectrum (7 hours)
Module 12	—	Capacitors and Capacitive Reactance (6 hours)
Module 13	—	Magentism (4 hours)
Module 14	—	Inductors and Inductive Reactance (5 hours)
Module 15	—	Transformers (4 hours)
Module 16	—	Relays (3 hours)
Module 17	—	Microphones and Speakers (3 hours)
Module 18	—	Meter Movements and Circuits (5 hours)
Module 19	—	Motors and Generators (7 hours)

This block contains both teacher and student materials. Printed instructor materials include a plan of instruction detailing the units of instruction, duration of the lessons, criterion objectives, and support materials needed. Student materials include a student text used for all the modules; nine guidance packages containing objectives, assignments, and review exercises for each module; and two programmed texts on AC computation and frequency spectrum and transformers. A digest of modules 11—19 for students who have background in these topics and need only a review of the major points of instruction is also provided.

This material is designed for self- or group-paced instruction to be used with the remaining nine blocks. Most of the materials can be adapted for individualized instruction. Some additional military manuals and commercially produced texts are recommended for reference, but are not provided. Audiovisuals suggested for use with the entire course consist of 143 videotapes which are not provided.

PLAN OF INSTRUCTION
(Technical Training)

ELECTRONIC PRINCIPLES

(Modular Self-Paced)

KEESLER TECHNICAL TRAINING CENTER

6 November 1975 - Effective 6 January 1976 with Class 760106

Volume 2

7-6

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DEPARTMENT OF THE AIR FORCE
USAF Sch of Applied Aerosp Sci (ATC)
Keesler Air Force Base, Mississippi 39534

PLAN OF INSTRUCTION 3AQR30020-1
6 November 1975

FOREWORD

1. PURPOSE: This publication is the plan of instruction (POI) when the pages shown on page A are bound into a single document. The POI prescribes the qualitative requirements for Course Number 3AQR30020-1, Electronic Principles (Modular Self-Paced) in terms of criterion objectives and teaching steps presented by modules of instruction and shows duration, correlation with the training standard, and support materials and guidance. When separated into modules of instruction, it becomes Part I of the lesson plan. This POI was developed under the provisions of ATCR 50-5, Instructional System Development, and ATCR 52-7, Plans of Instruction and Lesson Plans.

2. COURSE DESIGN/DESCRIPTION. The instructional design for this course is Modular Scheduling and Self-Pacing; however, this POI can also be used for Group Pacing. The course trains both non-prior service airmen personnel and selected re-enlistees for subsequent entry into the equipment oriented phase of basic courses supporting 303XX, 304XX, 307XX, 309XX and 328XX AFSCs. Technical Training includes electronic principles, use of basic test equipment, safety practices, circuit analysis, soldering, digital techniques, microwave principles, and troubleshooting of basic circuits. Students assigned to any one course will receive training only in those modules needed to complement the training program in the equipment phase. Related training includes traffic safety, commander's calls/briefings and end of course appointments.

3. TRAINING EQUIPMENT. The number shown in parentheses after equipment listed as Training Equipment under SUPPORT MATERIALS AND GUIDANCE is the planned number of students assigned to each equipment unit.

4. REFERENCES. This plan of instruction is based on Course Training Standard KE52-3AQR30020-1, 27 June 1975 and Course Chart 3AQR30020-1, 27 June 1975.

FOR THE COMMANDER

W. H. Horne

W. H. HORNE, Colonel, USAF
Commander
Tech Tng Gp Prov, 3395th

OPR: Tech Tng Gp Prov, 3395th
DISTRIBUTION: Listed on Page A

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
II	AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)

1. AC Computation and Frequency Spectrum (Module 11) — 7 (5/2)

a. Given a waveform that represents alternating current, identify its characteristics in terms of cycle; period; alternation; amplitude. CTS:4a Meas: W

(1) Define alternating current

(2) Label a sine wave to show a/an

(a) cycle

(b) period

(c) alternation (positive and negative half cycles)

(d) peak-to-peak amplitude

b. Given either the effective, average, peak, or peak-to-peak sine wave voltage and formulas, compute the other values. CTS: 4a Meas: W

(1) Define the effective, average, peak and peak-to-peak values of a sine wave.

(2) Select any one of the sine wave values and show use of formulas to solve for the other values.

(3) Compare effective (RMS) AC voltage to DC voltage.

Given a pictorial representation of the frequency spectrum, identify the ranges of power, radio, audio, and microwave frequencies. CTS: 4b Meas: W

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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ATC FORM APR 75 133 REPLACES ATC FORM 337 MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

COURSE CONTENT

(1) Explain how frequencies are grouped for electronic applications.

(2) Identify ranges and general use of each group.

d. Given either the frequency, period, or wavelength of a sine wave and formulas, compute the other values. CTS: 4c(1),(2),(3),(4) Meas: W

(1) Show relationships of time, frequency and wavelength.

(2) Identify or derive formulas for computing unknown values.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-11, AC Computation and Frequency Spectrum
KEP-ST-11, AC Circuits
KEP-107
KEP-PT-11, AC Computation and Frequency Spectrum
Audio Visual Aids
TVK-30-200, Definition of Analysis of AC
TVK-30-252, Frequency Spectrum
TVK-30-705, Waveform Analysis

Training Methods
Discussion (5 hrs) and/or Programmed Self Instruction
CTT Assignment (2 hrs)

Instructional Guidance
Issue KEP-GP-11 and KEP-ST-11. Give students practice in selecting or deriving the correct formula for finding the unknown value. Be especially watchful for correct use of powers of ten. Many students will correctly handle the mathematical process, but will have trouble with the placement of the decimal point. Assign objectives for CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER II	BLOCK TITLE AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)
2. Capacitors and Capacitive Reactance (Module 12)	6 (5/1)

a. From a group of statements, select the ones which describe the physical characteristics of a capacitor. CTS: 4a Meas: W

- (1) Basic capacitor construction
- (2) Types of variable capacitors
    - (a) Rotor-stator capacitor
    - (b) Compression capacitor
- (3) Types of fixed capacitors
    - (a) Electrolytic
    - (b) Paper
    - (c) Oil
    - (d) Mica
    - (e) Ceramic

b. From a group of statements, select the ones which describe the electrical characteristics of a capacitor. CTS: 4a Meas: W

- (1) Define "capacitance."
- (2) Describe capacitor action for
    - (a) direct current
    - (b) alternating current

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(3) Total capacitance

(a) Series

(b) Parallel

(c) Series-parallel

c. From a group of statements, select the one which describes the phase relationship of current and voltage in a capacitor, CTS: 4a Meas: W

(1) Phase relationship for direct current

(2) Phase relationship for alternating current

d. Given a list of statements, select the ones which describe the effect of varying frequency and capacitance on capacitive reactance. CTS: 4d Meas: W

(1) Define "capacitive reactance."

(2) Factors affecting capacitive reactance.

(a) Frequency

(b) Capacitance

e. Given the signal frequency, formulas, and the value of three capacitors in a series-parallel configuration, compute the total capacitance and total capacitive reactance. CTS: 4d Meas: W

(1) Calculate total capacitance in series-parallel.

(2) Calculate total capacitive reactance in

(a) series

(b) parallel

(c) series-parallel

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-12, Capacitors and Capacitive Reactance
KEP-ST-II
KEP-107
KEP-110

Audio Visual Aids
TVK 30-255, Capacitors and Capacitive Reactance

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

Training Equipment
AC Inductor and Capacitive Trainer 5967 (1)
Sine-Square Wave Generator 4864 (1)
Multimeter (1)
Meter Panel 4568 (1)

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
Performance (1 hr)
CTT Assignment (1 hr)

Multiple Instructor Requirements
Equipment (2)

Instructional Guidance
Issue KEP-GP-12. Supervise performance of laboratory exercise. This exercise supports objective 2d. Insure that all safety practices are followed. Assign objectives to be covered during CTT time.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER II	BLOCK TITLE AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)
3. Magnetism (Module 13)	4 (3/1)

a. Given a list of statements about magnetism, select the one which describes poles; magnetic field; flux density; permanent magnet; retentivity; permeability; reluctance; electromagnet; magnetic induction. CTS: 11f Meas: W

(1) Define "Magnetism."

(2) Magnets

(a) Natural

(b) Artifical

1 Permanent

2 Temporary

(3) Magnetism terms

(a) Retentivity

(b) Reluctance

(c) Permeability

(4) Magnetic field

(a) Characteristics of flux lines

(b) Law of magnetic attraction and repulsion

(c) Magnetic poles

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(5) Theories of magnetism

  (a) Weber's Theory

  (b) Domain Theory

(6) Electromagnetism

  (a) Define "Electromagnet."

  (b) Left hand thumb rule

    1 Straight wire

    2 Coil of wire

  (c) Factors determining strength of electromagnet

  (d) Define "Saturation."

(7) List requirements for a magnetic inductor.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-13, Magnetism
KEP-ST-II
KEP-107
KEP-110

Audio Visual Aids
TVK-30-165, Magnetism

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Issue KEP-GP-13. There are many new terms introduced in this lesson. Insure that students understand their meaning and relationship to the subject of magnetism. Assign objectives to be accomplished during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER II	BLOCK TITLE AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)
4. Inductors and Inductive Reactance (Module 14)	5 (4/1)

a. From a group of statements, select the ones which describe the physical characteristics of an inductor. CTS: 4a Meas: W

(1) Define "Inductance."

(2) Define "counter-electromotive force."

(3) Requirements for induction.

(4) Factors that determine inductance.

b. From a group of statements, select the ones which describe the electrical characteristics of an inductor. CTS: 4a Meas: W

(1) Total inductance.

(a) Series

(b) Parallel

(c) Series-parallel

c. From a group of statements, select the one which describes the phase relationship of current and voltage in an inductor. CTS: CTS: 4a Meas: W

(1) Inductor current and voltage

(a) Variable direct current power source.

1 First instant

2 After first instant

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(b) Alternating current power source.

d. Given a list of statements, select the ones which describe the effect of varying frequency and inductance on inductive reactance. CTS: 4d Meas: W

(1) Define inductive reactance.

(2) Show how inductive reactance is affected by changes in

(a) frequency.

(b) inductance.

e. Given the signal frequency, formulas, and the value of three inductors in a series-parallel configuration, compute the total inductance and the total inductive reactance. CTS: 4d Meas: W

(1) Compute total inductance in

(a) series.

(b) parallel.

(c) series-parallel.

(2) Compute total inductance reactance in

(a) series.

(b) parallel.

(c) series-parallel

5. Measurement and Critique (Part 1 of 2 Parts) 1

a. Measurement test

b. Test Critique

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-14, Inductors and Inductive Reactance
KEP-ST-II
KEP-107
KEP-110

Audio Visual Aids
TVK-30-253, Inductance and Inductive Reactance
TVK-30-205, Inductance

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

Training Equipment
AC Inductor and Capacitive Trainer 5967 (1)
Sine-Square Wave Generator 4864 (1)
AC Meter Panel 4568 (1)
Multimeter AN/PSM-6 (1)

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
Laboratory (1 hr)
CTT Assignment (1 hr)

Multiple Instructor Requirements
Equipment and Safety (2)

Instructional Guidance
Issue KEP-GP-14. Monitor laboratory exercise to insure correct use of equipment and safety practices. Inform students that a measurement test must be taken covering modules 11 through 14. Assign objectives to be accomplished outside of classroom during CTT time.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR		COURSE TITLE Electronic Principles
BLOCK NUMBER II	BLOCK TITLE AC Circuits	

1 COURSE CONTENT	2 DURATION (Hours)
6. Transformers (Module 15)	4 (3/1)

6. Transformers (Module 15)

a. Given a schematic diagram of a transformer with a resistive load, turns ratio, primary input voltage, and formulas, determine the output voltage; the reflected impedance; the phase relationships between secondary and primary voltages. CTS: 4h(3) Meas: W

(1) Explain electromagnetic induction in terms of

(a) mutual inductance

(b) flux linkage

(c) coefficient of coupling

(2) Transormer action.

(a) Turns ratio.

1 Step-up.

2 Step-down.

(b) Primary and secondary power.

(c) Reflected impedance.

(d) Phase shifts across transformers.

1 0°

2 180°

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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COURSE CONTENT

b. From their schematic representation, identify air core, iron core, auto, and multiple winding transformers. CTS: 4h(3) Meas: W

(1) Describe auto, power, audio and RF transformers in terms of

(a) physical characteristics

(b) electrical characteristics

(c) schematic symbols

c. From a list of statements, select the procedures for checking open and shorted transformers. CTS: 4h(3) Meas: W

(1) Ohmmeter checks for

(a) open winding

(b) shorted winding

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-15, Transformers
KEP-ST-II
KEP-107
KEP-110
KEP-PT-15, Transformers

Audio Visual Aids
TVK-30-254, Transformers

Training Methods
Discussion (3 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Issue KEP-GP-15. Assign objectives to be accomplished during CTT time.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles

BLOCK NUMBER II	BLOCK TITLE AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)

7. Relays (Module 16) — 3 (2/1)

a. Given a group of statements, select the one that describes the operation of a relay. CTS: 11a Meas: W

(1) Describe electromagnetic relay

(a) Construction

(b) Operation

b. Given a relay schematic with or without coil current, determine which contacts will be open and which will be closed. CTS: 11a Meas: W

(1) Schematic diagram

(a) Single pole single throw (SPST) relay

1 Normally open contacts (NO)

2 Normally closed contacts (NC)

(b) Single pole double throw (SPDT) relay

(2) Electrical states of a relay

(a) De-energized.

(b) Energized.

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

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PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-16, Relays
KEP-ST-II
KEP-107
KEP-110

Audio Visual Aids
TVK-30-166, Relays and Vibrators

Training Methods
Discussion (2 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Issue KEP-GP-16. Assign objective to be covered during CTT time.

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PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE Electronic Principles
BLOCK NUMBER II	BLOCK TITLE AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)
8. Microphones and Speakers (Module 17)	3 (2/1)

a. Given a group of statements, select the one that describes the operation of a speaker. CTS: 11d Meas: W

- (1) Define loudspeaker
- (2) Earphones
  - (a) Construction
  - (b) Operation
- (3) Dynamic speaker
  - (a) Definition
  - (b) Construction
  - (c) Operation

b. Given a group of statements, select the one that describes the operation of a microphone. CTS: 11d Meas: W

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
3AQR30020-1	6 November 1975	37

ATC FORM APR 75 133 ATC Keesler 6-1039 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED

COURSE CONTENT

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-17, Microphones and Speakers
KEP-ST-II
KEP-107
KEP-110

Training Methods
Discussion (2 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

Instructional Guidance
Issue KEP-GP-17. Assign objectives to be accomplished during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
II	AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)
9. Meter Movements and Circuits (Module 18)	5 (4/1)

a. From a group of statements related to meter movements select the one which describes the function of the permanent magnet; the moving coil; the spiral spring; the pointer; the scale. CTS: 2d Meas: W

- (1) Moving coil meter
    - (a) Characteristics
    - (b) Component parts
    - (c) Operation
    - (d) Schematic symbol
    - (e) Meter sensitivity

b. From a group of statements related to multimeters, select the one which describes the function of the shunt resister; the multiplier resistor; the ohms zero adjust resistor. CTS: 2d Meas: W

- (1) Ammeter operation
    - (a) Shunt resistor
    - (b) Circuit connection
    - (c) Meter sensitivity
- (2) Voltmeter operation
    - (a) Multiplier resistor

SUPERVISOR APPROVAL OF LESSON PLAN (PART II)

SIGNATURE	DATE	SIGNATURE	DATE

PLAN OF INSTRUCTION NO.	DATE	PAGE NO.
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ATC FORM APR 75 133 ATC Keesler 6-1039 REPLACES ATC FORMS 337, MAR 73, AND 770, AUG 72, WHICH WILL BE USED.

PLAN OF INSTRUCTION/LESSON PLAN PART I (Continuation Sheet)

COURSE CONTENT

(b) Circuit connection

(c) Meter sensitivity

(3) Ohmmeter operation

(a) Ohm's zero adjust

(b) Circuit connection

(c) Ohmmeter scale

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-18, Meter Movements and Circuits
KEP-ST-II
KEP-107
KEP-110

Audio Visual Aids
LFK 0-30-6, Basic Meter Movements
LFK 0-30-7, Amp Meters
LFK 0-30-8, Volt Meters
LFK 0-30-9, Ohm Meters

Training Methods
Discussion (4 hrs) and/or Programmed Self Instruction
CTT Assignments (1 hr)

Instructional Guidance
Issue KEP-GP-18. Assign objectives to be accomplished during CTT time.

PLAN OF INSTRUCTION/LESSON PLAN PART I

NAME OF INSTRUCTOR	COURSE TITLE
	Electronic Principles

BLOCK NUMBER	BLOCK TITLE
II	AC Circuits

1 COURSE CONTENT	2 DURATION (Hours)
10. Motors and Generators (Module 19)	7 (6/1)

a. Given a list of statements about motors and generators, select the one which identifies the purpose of the field coil; the armature; the rotor; the brushes; the slip rings; the commutator; the pole pieces. CTS: 11b Meas: W

(1) Basic Generator concepts.

(a) Requirements for magnetic induction

(b) Direction of current flow

(c) Magnitude of induced voltage

(d) Components of AC generator

(e) Components of DC generator

(2) Using a pictorial diagram, identify the basic components and state their purpose.

b. Given a group of statements, select the ones that describe the operation of a motor. CTS: 11b Meas: W

(1) Define motor.

(2) Explain force exerted between magnetic fields.

(3) Define torque.

(4) Define counter-electromotive force.

(5) Show two phase and three phase motor operation.

(6) Explain differences in AC and DC

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c. Given a group of statements, select the ones that describe the operation of a generator. CTS: 11b Meas: W

(1) Compare the operation of a generator with the operation of a motor.

SUPPORT MATERIALS AND GUIDANCE

Student Instructional Materials
KEP-GP-19, Motors and Generators
KEP-ST-II
KEP-107
KEP-110

Audio Visual Aids
TVK 30-201, AC Generators
TVK 30-202, DC Generators
TVK 30-703, DC Motors
TVK 30-704, AC Motors

Training Methods
Discussion (6 hrs) and/or Programmed Self Instruction
CTT Assignment (1 hr)

11.	Related Training (identified in course chart)	2
12.	Measurement and Critique (Part 2 of 2 Parts)	1

a. Measurement test

b. Test critique

Instructional Guidance
Issue KEP-GP-19. Assign objectives to be accomplished during CTT time. Inform students that Part 2 of the measurement test covers modules 15 through 19.

ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP ST/DIGEST II

Technical Training

Electronic Principles (Modular Self-Paced)

Block II

DIGEST

1 April 1975

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

Student Text 3AQR3X020-X
KEP-ST/DIGEST I-III
1 April 1975

DIGESTS

The digest is designed as a refresher for students with electronics experience and/or education who may not need to study any of the other resources in detail.

After reading a digest, if you feel that you can accomplish the objectives of the module, take the module self-check in the back of the Guidance Package. If you decide not to take the self-check, select another resource and begin study.

CONTENTS

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4	Direct Current and Voltage	3
5	Resistance, Resistors, and Schematic Symbols	4
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8	Parallel Resistive Circuits	10
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10	Troubleshooting DC Resistive Circuits	12
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MODULE 11

AC COMPUTATION AND FREQUENCY SPECTRUM

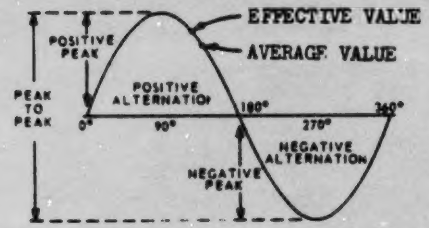
In previous lessons, you studied current which flows in one direction only. Now, you are ready to take up current which alternately flows in two directions.

ALTERNATING CURRENT (AC).

Alternating current is the term applied to current which periodically reverses its direction.

The sine wave is the most common AC waveform. In fact, the sine wave is so widely used that when we think of AC, we automatically think of the sine wave. Household

AC is a sine wave. Let us examine an AC sine wave using the figure.



Notice that the horizontal line divides the sine wave into two equal parts -- one above the line and the other below it. The portion above the line represents the POSITIVE ALTERNATION and the portion below the line represents the NEGATIVE ALTERNATION. The sine wave continuously changes amplitude and periodically reverses direction. Notice that the wave reaches its maximum swing from zero at 90° and 270°. Each of these points is called the PEAK of the sine wave. When we speak of the PEAK AMPLITUDE of a sine wave, we mean the maximum swing, or the height of one of the alternations at its peak. These terms apply to either current or voltage and are important to remember because you will be using them throughout your electronics career.

Next, let us take the term: PEAK-to-PEAK. This term, as you can see in the figure, represents the difference in value between the positive and negative peaks of the wave. Of course, this is equal to twice the peak value: $E_{pk-pk} = 2\ E_{pk}$ for a sine wave.

Another useful value for the sine wave is the EFFECTIVE value. The effective value of a sine wave is the amount which produces the same heating effect as an equal amount of DC. Since the heating effect of current is proportional to the square of the current, we can calculate the effective value by squaring the instantaneous values of all the points on the sine wave, taking the average of these values, and extracting the square root. The effective value is, thus, the root of the mean (average) square of these values. This value is known as the ROOT-MEAN-SQUARE, or rms value. When we speak of household voltage as having a value of 110 volts, we mean that it has an effective or rms value of 110 volts. Unless otherwise stated, AC voltage or current is expressed as the effective value.

A sine wave with a peak amplitude of 1 volt has an effective value of .707 volts. This means that a sine wave of voltage whose peak value is 1 volt will have the same heating effect as .707 volts of DC. To find the effective value of a sine wave, multiply the peak value by .707.

$$E_{eff} = .707\ E_{pk}$$

The reciprocal of .707 is 1.414. Therefore, to find the peak value of a sine wave multiply the effective by 1.414:

$$E_{pk} = 1.414\ E_{eff}$$

Another sine wave value that is important to know is the AVERAGE value. This is the average of the instantaneous values of all points in a SINGLE alternation. (The average of a complete sine wave is zero).

Refer to the figure; the AVERAGE height of a single alternation is .637 times the peak value. In other words, $E_{ave} = .637\ E_{pk}$. The relationship between the average and effective values can be determined mathematically and is shown in the following formula:

$$E_{ave} = .9\ E_{eff}$$

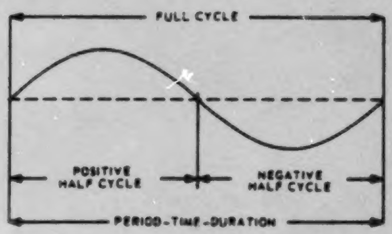
The reciprocal of .9 is 1.11. Therefore, the effective voltage is 1.11 times the average voltage:

$$E_{eff} = 1.11\ E_{ave}$$

CONVERT FROM	TO GET			
	RMS EFFECTIVE	AVERAGE	PEAK	PEAK TO PEAK
RMS EFFECTIVE		0.900	1.414	2.828
AVERAGE	1.110		1.570	3.141
PEAK	0.707	0.637		2.000
PEAK TO PEAK	0.354	0.318	0.500	

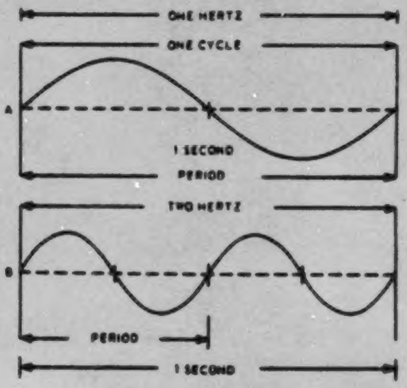
The voltage relationships of a sine wave are summarized in the chart above.

Alternating current periodically reverses direction. We call two consecutive alternations, one positive and one negative, a CYCLE. We often refer to the positive and negative alternations as HALF-CYCLES. In describing the sine wave, we could say that during the positive half-cycle it rises from zero to maximum positive and then returns to zero, and that during the negative half-cycle it drops to a maximum negative value and then returns to zero.

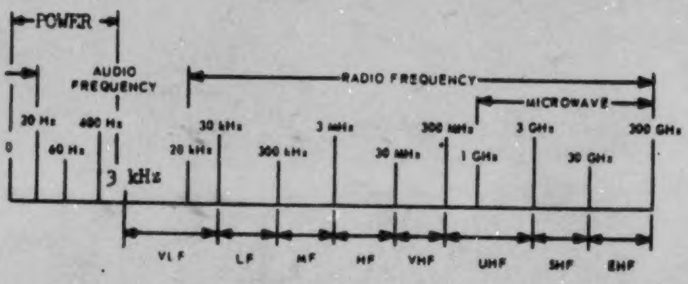


Alternations of AC do not happen instantaneously, they take TIME. The term PERIOD is used to define the time of one cycle of alternating current. Another term having the same meaning as time and period is DURATION. The DURATION of one cycle is one-sixtieth of a second, or, "One cycle has a PERIOD of one-sixtieth of a second;" or "One-sixtieth of a second is the TIME of one cycle." All three terms have the same meaning.

Alternating currents commonly used in aircraft have a period of one four-hundredth of a second. This means that one cycle takes one four-hundredth of a second and in one second there are four hundred complete cycles. The number of cycles in one second brings up a new term - FREQUENCY. The frequency of an AC is the number of cycles that occur in one second. This brings us to another term - HERTZ. HERTZ is a UNIT OF FREQUENCY EQUAL TO ONE CYCLE PER SECOND. Instead of saying sixty cycles per second, we will say sixty Hertz (Hz).



As you can see in the figure, there is a definite relationship between the period of an alternating current and the frequency of the current. Sine wave B has a period that is one-half the period of sine wave A, and a frequency that is twice the frequency of sine wave A. As the period for one cycle



becomes shorter, the frequency increases or as the frequency increases, the period of one cycle becomes shorter.

Frequencies are classified as to their usage. See the figure above.

Wavelength is the distance traveled by a wave during the period of one cycle and is measured in meters. Wavelength involves two factors: speed and time. Speed is the rate of movement or, velocity. Electromagnetic waves move away from a source at a velocity of 300 million meters per second. Time is the period of one cycle and is determined by the frequency of the wave. This is expressed by the relationship:

$$t = \frac{1}{f}$$

The symbol for wavelength is the Greek letter Lambda (λ). It is equal to VELOCITY (V) times TIME (t). The formula is:

$$\lambda = Vt$$

Substituting frequency for time, the wavelength may also be expressed as:

$$\lambda = \frac{V}{f}$$

MODULE 12

CAPACITORS AND CAPACITIVE REACTANCE

Capacitance is present any time two conductors are separated by an insulator. A capacitor consists of two conducting plates separated by a dielectric (insulator). The physical properties of a capacitor that effect its values of capacitance include: (1) the plate surface area; (2) spacing between the plates; (3) dielectric constant of the insulator. Their relationship can be shown by the formula:

$$C = \frac{kA}{D}$$

C = capacitance

k = dielectric constant

D = dielectric thickness (separation between the plates)

A = plate area

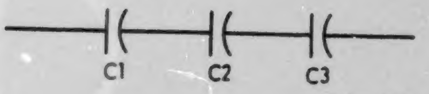
In addition to its measure of capacity, every capacitor has a working voltage rating which is determined by the type of dielectric and its thickness. The working voltage of a capacitor refers to the maximum DC voltage values which can be applied to the capacitor continuously. A capacitor marked 600V DC should be expected to withstand a continuous application of 600V DC without damage. If working with AC voltage, the peak voltage value must be considered. Any combination of AC and DC voltages must not exceed the voltage rating.

In many circuits, capacitors are connected in series, parallel, or series-parallel. To determine the capacitance of a circuit, we must be familiar with the rules for calculating the total capacitance for the three common circuit configurations.

SERIES

For two or more capacitors wired in series, as shown, the total capacitance is smaller than any of the individual capacitances. The total capacitance can be calculated with the formula:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

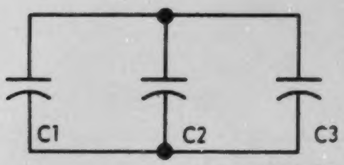


REP4-974

PARALLEL

For capacitors wired in parallel, total capacitance can be calculated with the formula:

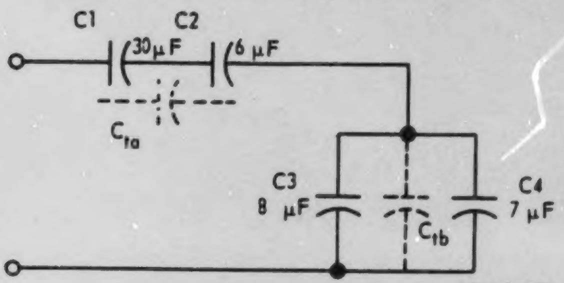
$$C_T = C1 + C2 + C3 + \ldots$$



REP4-97

SERIES-PARALLEL

In series-parallel circuits, total capacitance can be calculated by dividing the series-parallel network into simple series or parallel circuits and solving each independently. Then, combine the independent solutions (equivalent circuits) using the rule for series circuits.



REP4-976

Series equivalent of C1 and C2

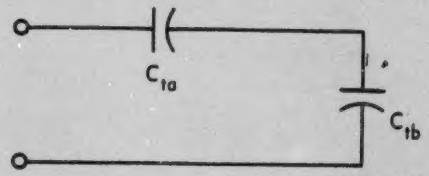
$$C_{ta} = \frac{1}{\frac{1}{C1} + \frac{1}{C2}}$$

Parallel equivalent of C3 and C4

$$C_{tb} = C3 + C4$$

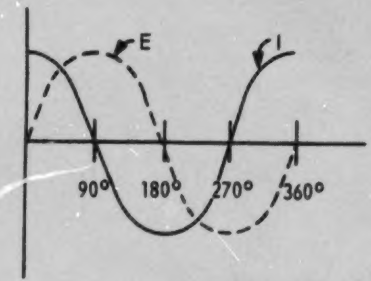
Total capacitance of C_{ta} and C_{tb} (in series)

$$C_t = \frac{1}{\frac{1}{C_{ta}} + \frac{1}{C_{tb}}}$$



REP4-977

A capacitor in an AC circuit causes a phase difference, between voltage and current. The figure represents the AC waveform of both current and voltage in a purely capacitive, idealized circuit. Notice that current and voltage are 90° out of phase. Current leads voltage by 90°.



REP4-978

Capacitive reactance is the opposition by a capacitor to the flow of alternating current. The two factors which govern capacitive reactance are frequency of the applied voltage and the value of the capacitance in the circuit. Their relationship is shown by the formula:

$$X_C = \frac{1}{2\pi fC}$$

X_C = capacitive reactance

2π = 6.28

f = frequency of the applied voltage

C = capacitance in the circuit.

Total capacitive reactance can be computed for any circuit once total capacitance has been determined.

MODULE 13

MAGNETISM

Magnetism, like electricity, is an invisible force which has been known to man for centuries and yet no one knows the full details as to what causes it. Magnetism can be described as the property of a material that enables it to attract ferrous material as well as other magnetic material such as iron, steel, nickel, and cobalt. Magnets can be classified into two general types, temporary and permanent. A temporary magnet will have magnetic qualities for only a short time while a permanent magnet will hold its magnetic strength for a very long period, practically indefinately. A magnet will have two poles, a NORTH POLE and a SOUTH POLE. Imaginary lines called magnetic lines of force leave the north pole, and enter the south pole as shown in Figure 1.

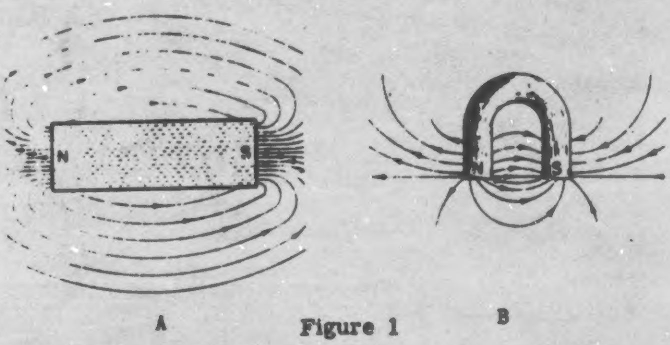


Figure 1

The number of lines would indicate the strength of this MAGNETIC FIELD. By reshaping the bar magnet of Figure 1A to the horseshoe shaped magnet in Figure 1B, the magnetic field is more concentrated. The ends of the bar form the poles, every magnet will have a north pole and a south pole. When the number of magnetic lines is expressed in terms of unit area it is called FLUX DENSITY.

Some materials can pass magnetic lines of force easier than others. The ease with which these lines are passed is called PERMEABILITY. An alloy called permaloy has a much greater permeability than iron. The ability of a material to resist the magnetic lines is called RELUCTANCE and is similar to electrical resistance.

One method of making a temporary magnet is to wrap a piece of material, called a core, with a conductor and pass an electric current through it. This would be called an ELECTROMAGNET and is shown in Figure 2.

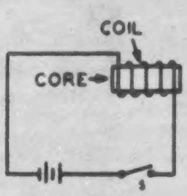


Figure 2

The current passing through the conductor is called the MAGNETIZING FORCE. When the current is removed the core material will retain some of the magnetic force.

Different types of core material will be able to retain the magnetic force for different periods of time. The ability to retain the magnetic force is called RETENTIVITY. The amount of magnetic force left is called RESIDUAL MAGNETISM.

Another method of magnetizing an unmagnetized bar of magnetic material is by MAGNETIC INDUCTION. This can be accomplished by stroking the unmagnetized bar with a magnet.

MODULE 14

INDUCTORS AND INDUCTIVE REACTANCE

Inductance is the property of a circuit which opposes any change in current flow.

An inductor is basically a coil of wire. There are four physical factors which affect the inductance of a single-layer coil. They include: (1) the number of turns in the coil, (2) the diameter of the coil, (3) the coil length, and (4) the type of material used for the core.

Their relationship can be shown by a formula:

$$L = \frac{N^2 \mu A}{l}$$

L = Inductance

N = Number of turns

A = Cross-Sectional area of the core

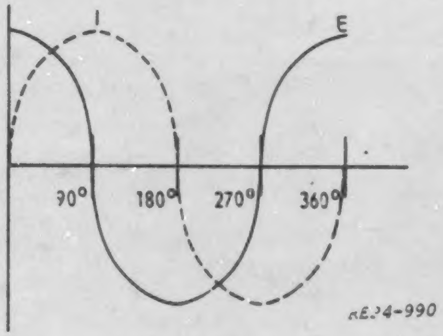
μ = Permeability of the core material

l = Length of the coil

The unit of Inductance (L) of a coil is the henry (H). A coil which develops a CEMF of one volt when the current is changing at the rate of one ampere per second has an inductance of one henry.

An inductor in an AC circuit causes a phase difference between current and voltage.

The figure represents the AC waveform of both current and voltage in a purely inductive, idealized circuit. Notice that current and voltage are 90° out of phase. Current lags the voltage by 90°. (See figure below).



Inductive reactance is the opposition an inductor offers to the flow of alternating current. The two factors which govern inductive reactance are frequency of the applied EMF and the value of the inductance in the circuit. Their relationship can be shown by the formula:

$$X_L = 2\pi f L$$

X_L = Inductive reactance

2π = 6.28

f = frequency of the applied EMF

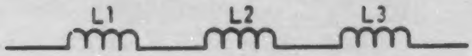
L = Inductance in the circuit

In many circuits, inductors occur in series, parallel, and series-parallel configurations. To determine the total inductance of a circuit, we must calculate inductance for the three common circuit configurations.

SERIES

For two or more inductors wired in series, as shown, the total inductance for the circuit below can be calculated with the formula:

$$L_t = L1 + L2 + L3 + \ldots$$

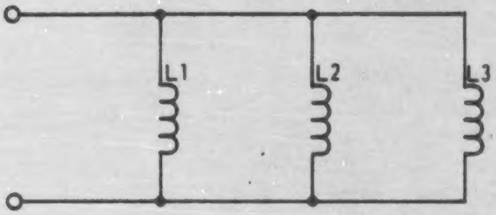


REP4-991

PARALLEL

For two or more inductors wired in parallel, as shown, total inductance can be calculated with the formula:

$$L_t = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3} + \ldots}$$



REP4-992

SERIES-PARALLEL

In series-parallel circuits, total inductance can be calculated by reducing the series-parallel network to simple series and parallel circuits and then solving the resulting equivalent circuit.

Series Equivalent of L1 and L2 = L_{t_a}

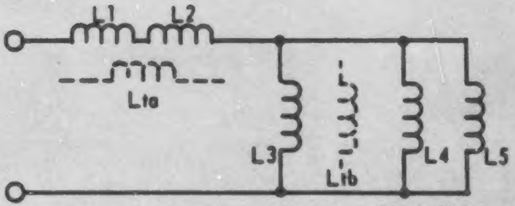
$= L1 + L2$

Parallel Equivalent of L3, L4 and L5

$$= L_{t_b} = \frac{1}{\frac{1}{L3} + \frac{1}{L4} + \frac{1}{L5}}$$

Total Inductance: $L_t = L_{t_a}$ Series Equivalent

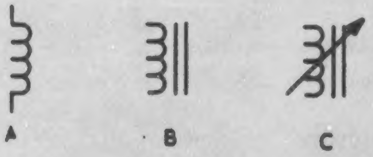
$+ L_{t_b}$ Parallel Equivalent



REP4-993

Total circuit inductive reactance can be computed after total circuit inductance has been found.

Symbols for inductors in electronic circuit diagrams are:

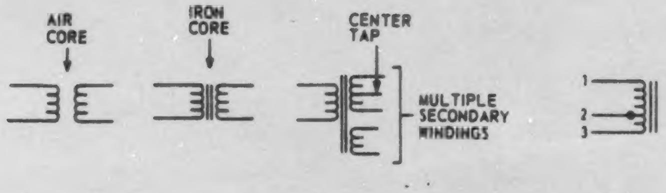


REP4-994

"A" has an air core, "B" has a fixed magnetic core, and "C" has a variable magnetic core.

Inductor Losses

There are three types of power loss in inductors: Copper, hysteresis, and eddy current losses. Copper loss can be reduced by increasing the size of the conductor. Hysteresis loss can be reduced by using high permeability material for the core. Eddy current loss can be reduced by laminating the core.



MODULE 15

TRANSFORMERS

A transformer is a device that transfers electrical energy from one circuit to another by electromagnetic induction.

Transformer schematic symbols above are drawn in reference to the construction.

Air-core transformers are commonly used in circuits carrying radio-frequency energy.

Iron-core transformers are commonly used in audio and power circuits.

Multiple secondary winding types are commonly used in power supply circuits.

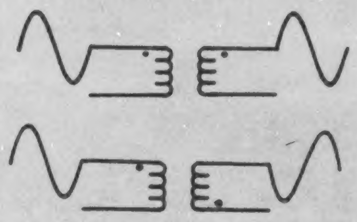
Auto-transformers are used where we do not need the electrical isolation of separately insulated primary and secondary windings.

A transformer can be connected to step-up or step-down voltage. The turns ratio of the primary to secondary will determine its use in the circuit.

The behavior of ideal transformers can be calculated from the following set of basic equations:

Voltage-Turns relationship	$\frac{E_p}{E_s} = \frac{N_p}{N_s}$
Voltage-Current relationship	$\frac{E_p}{E_s} = \frac{I_s}{I_p}$
Current-Turns relationship	$\frac{N_p}{N_s} = \frac{I_s}{I_p}$
Impedance-Turns relationship	$\frac{Z_p}{Z_s} = \frac{(N_p)^2}{(N_s)^2}$
Impedance-Voltage relationship	$\frac{Z_p}{Z_s} = \frac{(E_p)^2}{(E_s)^2}$
Impedance-Current relationship	$\frac{Z_p}{Z_s} = \frac{(I_s)^2}{(I_p)^2}$
Conservation of Energy relationship	$P_{pri} = P_{sec}$

From the schematic representation you can determine the phase relationship between secondary and primary voltage. The sense dots in the schematic indicate the ends of the windings which have the same polarity at the same instant of time.



The phase of the output voltage can be reversed by reversing the direction of one of the windings, or simply by reversing the leads to one of the windings. Where it is necessary to keep track of the phase relationship in a circuit, we mark one end of each winding with a sense dot.

An ohmmeter can be used to determine whether a transformer is open or shorted by comparing the resistance of the windings to a known specification. The best way to check a transformer is to apply the rated input voltage and compare the measured output voltage to its specification.

MODULE 16

RELAYS

A relay is an electromechanical device. Relays are made in many forms or sizes and used in many types of control circuits. All electromagnetic relays operate on the principle that a piece of soft iron called an armature is attracted to the pole of an electromagnet when the pole becomes energized. This armature can engage one or more switch contacts. These switch contacts can be arranged in various configurations such as: Single pole single throw (SPST), Double pole double throw (DPDT), Single pole double throw (SPDT), and many other combinations.

Normally open contacts (NO) and normally closed contacts (NC) refer to contact conditions when the relay is de-energized.

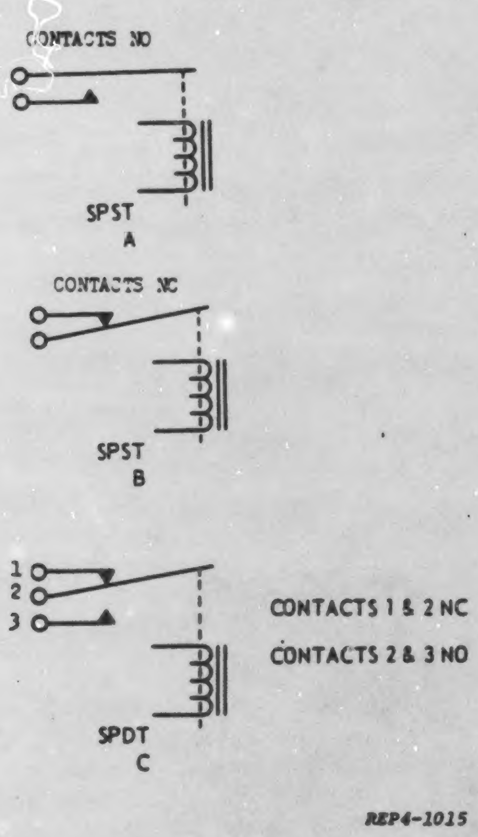


Figure 16-1

Figure 16-1 shows all relays in the de-energized condition with the contacts open or closed as indicated. When energized the normally open contacts will close and the normally closed contacts will open.

MODULE 17

MICROPHONES AND SPEAKERS

In order to hear any reproduced sound such as music or speech from a radio, TV, or stereo, a loudspeaker is used. A speaker converts electrical signals to sound waves. The speaker uses a cone shaped diaphragm which vibrates at the applied audio rate and produces the sound waves. All electrodynamic speakers employ the principle of the interaction of two magnetic fields, one produced by either a permanent magnet or an electromagnet, the other by the audio signal applied to a coil. See figure 1.

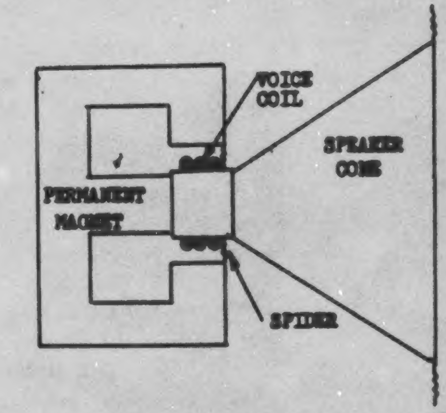


Figure 1

The coil (called a voice coil) is attached to the cone so that the cone will move back and forth according to the applied audio frequency or AC signal. The cone is held in place by a flexible device called a spider.

A headset, earpiece or earphone also applies the same principle. Instead of a cone shaped diaphragm, it may use a flat metal disk.

A microphone is the device used to convert sound waves to an electrical signal or audio frequency, which is then amplified to the desired level required for the specific application. Most types will use a diaphragm. The diaphragm, in turn, is fastened to some type of transducer which will generate the AC signal at the same frequency as the sound waves impressed on the diaphragm.

MODULE 18

METER MOVEMENTS AND CIRCUITS

You already have a good understanding of electromagnetism. Three classes of meter movements applying this principle are: moving-coil, moving-iron, and dynamometer. The most common meter movement is the moving coil and is often referred to as the d'Arsonval movement. See figure 1.

The principle of operation is as follows: Current flow through the moving (moveable) coil will cause a magnetic field which will interact with the magnetic field of the permanent magnet, causing a torque on the coil. The pointer is fastened to the moving coil and will indicate a certain reading on the calibrated scale. If more current passes through the coil, the pointer will deflect further until full scale deflection (FSD) is reached. Deflection is directly proportional to current flow. The sensitivity of any meter is dependent on the amount of current required for FSD.

The same meter movement can be used as an ammeter, voltmeter, or ohmmeter depending on how it is connected with other components. By proper switching any one of these three functions can be used. This type of meter is called a multimeter. The scales that could be used are shown in figure 2. Note that the same linear scale can be used for milliamperes or volts. The ohmmeter scale is inverse and non-linear.

In order to extend the range of the meter used for measuring a higher current a meter shunt resistor is used. This allows some of the current (I_s) to bypass the meter movement and go through the shunt resistor (R_s). The current going through the meter movement should never exceed the current required for FSD (I_m), but it will always be proportional to the current through the shunt resistor.

To determine the value of R_s, use Ohm's Law in this manner:

$$I_s R_s = I_m R_m,$$

where

$$I_s = I_t - I_m.$$

Example: $I_m = 1$ mA, $R_m = 100$ ohms, and $I_t = 10$ mA. Find the value of $R_s \cdot R_s = 11.1$ ohms.

When used as a voltmeter the current through the meter must again be limited to the FSD value. Adding a resistor in series with the meter movement will limit the current for the voltage being measured. This series resistor is called a multiplier resistor (R_x). The value of R_x can be determined by:

$$R_x = R_t - R_m,$$

where

$$R_t = \frac{E_a}{I_m}.$$

Example: Using the same meter movement of 1 mA FSD, R_x would have to be 99.9 k ohms to extend the voltmeter range to 100 volts.

To use this same meter movement as an ohmmeter a dry cell could be used as a voltage source. Two resistors are now used in series with the meter. One of the resistors is variable and is adjusted for FSD with the test leads of the ohmmeter shorted together. This compensates for the drop in voltage as the dry cell ages. The value of these resistors can be determined by applying Ohm's Law.

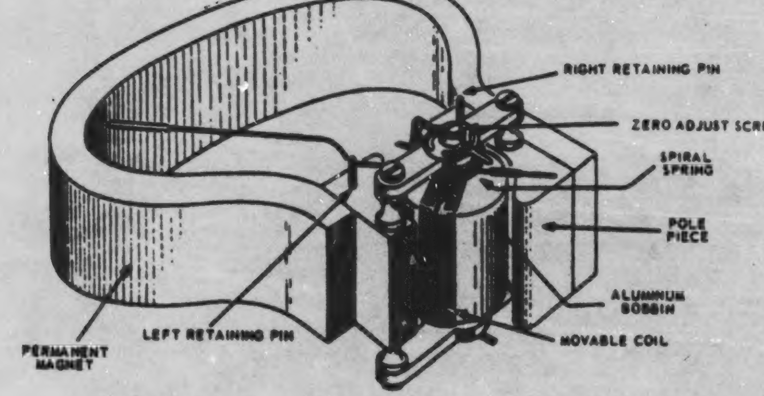


Figure 1

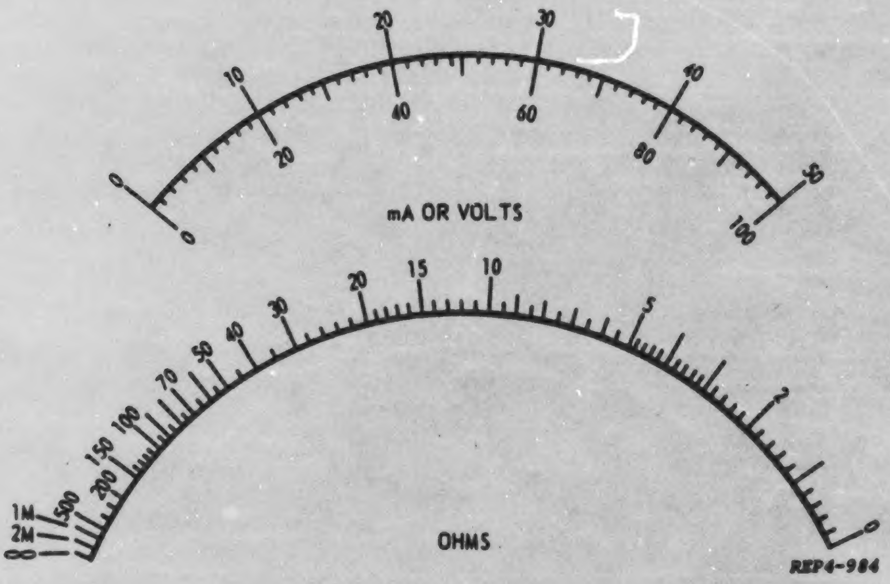
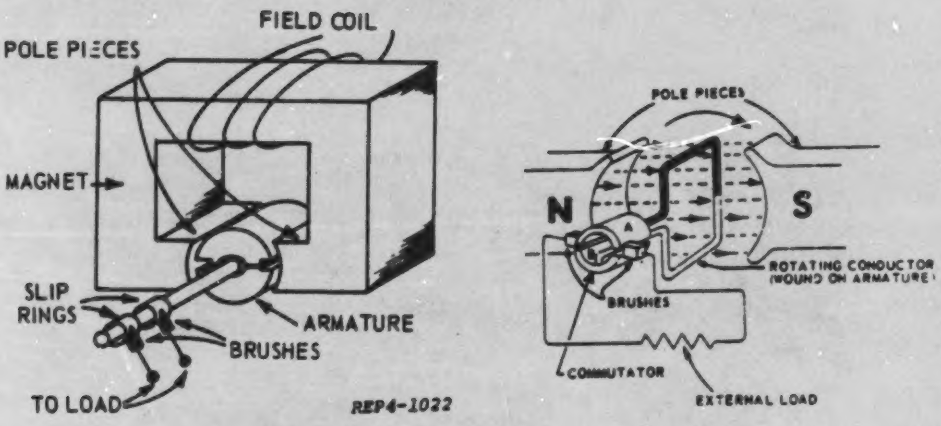


Figure 2



A. AC GENERATOR B. DC GENERATOR

Figure 1

MODULE 19

MOTORS AND GENERATORS

Two more devices that use electromagnetism are the generator and motor. The generator converts mechanical energy to electrical energy while the motor reverses this action.

Let us consider the generator action first. One or more conductors moving within a magnetic field, so as to CUT these lines, will produce an EMF. The conductors are wound on an armature or rotor. The ends of each loop connect either to two slip rings in an AC generator or to the segments of a commutator in the DC generator. Some mechanical power source must turn this armature. Brushes make contact with the revolving slip rings or commutator and connect the armature to the load device. See figure 1.

The magnetic field can be provided by an electromagnet or by a permanent magnet.

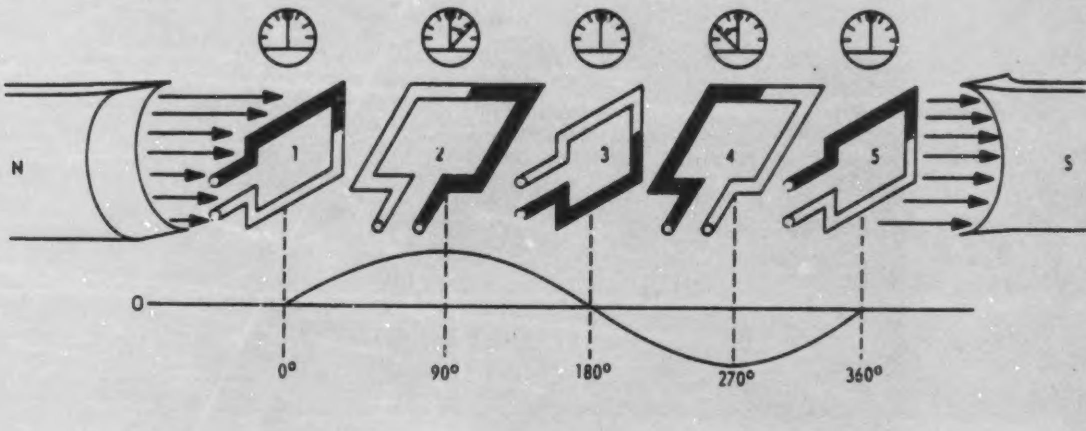


Figure 2

Pole pieces are used to concentrate the magnetic lines. The pole pieces and the armature core provide a low reluctance path.

With a single coil for the armature winding, a complete cycle of AC will be produced for each revolution. See figure 2. As the coil rotates from 0° it cuts the magnetic lines of force inducing an EMF in the coil. This EMF causes current to flow through the conductor, slip rings, brushes, and load. At the 90° position the conductor cuts the most lines per unit of time and thus maximum voltage is induced. At the 180° point the conductors move parallel to the magnetic lines and the output voltage will be zero. At 270° the output is maximum negative. At 360° point, the cycle will start over. Maximum amplitude is directly proportional to the speed of rotation and the strength of the magnetic field.

Now that the operation of the AC generator is understood, let's make a minor change to produce a DC output.

Applying the left-hand rule we can see that the direction of current flow in the conductor changes as coil rotates. This reversal takes place at the 0° and 180° positions. By a switching action this reversal of current through the load can be eliminated by replacing the two slip rings with a commutator. For a single loop armature winding a two segment commutator is used. If the armature winding has two loops then a four segment commutator would be used. One end of each loop is connected to a segment. Two brushes are used to make contact with the rotating commutator just as in the AC generator.

All motors operate on the interaction of magnetic fields. A force is exerted between a stator field and the field of the armature which is free to rotate. The amount and direction of this force will determine motor speed and direction of rotation. Speed is also a function of frequency and the number of pole pairs in the AC motor.

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Technical Training

Electronic Principles (Modular Self-Paced)

Volume II

AC CIRCUITS

1 November 1975

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ELECTRONIC PRINCIPLES BRANCH
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STUDENT TEXT 3AQR3X020-X
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Electronic Principles

Block 2

AC CIRCUITS

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Chapter 1

ALTERNATING CURRENT

1-1. In previous lessons, you studied current which flows in one direction only. Now, you are ready to take up current which alternately flows in two directions. ALTERNATING CURRENT (AC). Let us start by defining alternating current.

1-2. Alternating current is the term applied to current which periodically reverses its direction.

1-3. As you know, current supplied by a battery is direct current. This means, of course, that the current flows in one direction only. Therefore, it is UNIDIRECTIONAL. Alternating current, on the other hand, is BIDIRECTIONAL. That is, the electrons flow first in one direction and then in the opposite direction. If we were able to continuously reverse the polarity of a battery, we would have bidirectional, and thus alternating current.

1-4. Graphic representations of how voltage and current changes in amplitude and direction over a period of time, are called waveforms. Figure 1-1 shows various waveforms of alternating current. A special type of alternating current waveform is symmetrical. A waveform is symmetrical when the second half of the waveform is the mirror image of the first half of the waveform, but with reversed polarity. In figure 1-1, the square, circular, and sinewave waveforms are symmetrical.

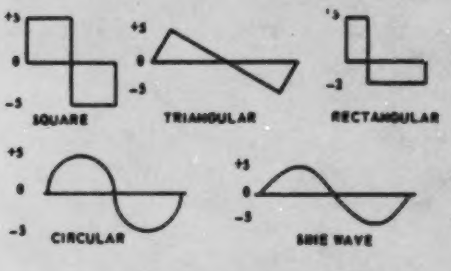

Figure 1-1. Alternating Current

1-5. The sine wave is the most common AC waveform. In fact, the sine wave is so widely used that when we think of AC, we automatically think of the sine wave. Household AC is a sine wave.

1-6. The shape of the sine wave is a plot of points generated when a radius line of a circle rotates through 360° (figure 1-2). The points are determined by the distance from the arrow of the radius to the horizontal (0° - 180°) reference line as the radius rotates counterclockwise through 360°. You can see that this distance is continually changing. Therefore, to describe the sine wave of alternating current, we must add the following to the previous definition.

1-7. Alternating current is CONTINUOUSLY changing in amplitude and periodically reversing direction.

1-8. Starting at zero, the sine wave increases to a maximum amplitude in one direction and then decreases to zero. It then increases to a maximum amplitude in the opposite direction and again decreases to zero. The sine wave of voltage or current is thus CONTINUOUSLY CHANGING IN AMPLITUDE and periodically reversing direction.

1-9. The sine wave of figure 1-2 is produced by plotting the sine values of a vector rotated through 360°. Therefore, it is called a SINE WAVE. The form or shape of the sine wave can represent either alternating voltage

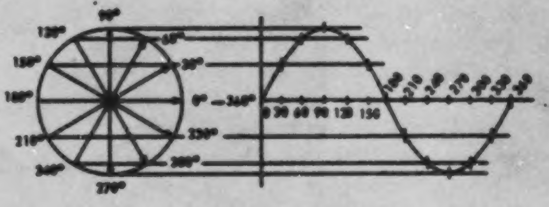

Figure 1-2. Sine Wave Generation

or alternating current. Let us examine an AC sine wave in greater detail, using figure 1-3.

1-10. Notice that the horizontal line divides the sine wave into two equal parts -- one above the line and the other below it. The portion above the line represents the POSITIVE ALTERNATION and the portion below the line represents the NEGATIVE ALTERNATION. Notice that the wave reaches its maximum swing from zero at 90° and 270°. Each of these points is called the PEAK of the sine wave. When we speak of the PEAK AMPLITUDE of a sine wave, we mean the maximum swing, or the height of one of the alternations at its peak. These terms apply to either current or voltage and are important to remember because you will be using them throughout your electronics career.

1-11. Next, let us take the term: PEAK-TO-PEAK. This term, as you can see in figure 1-3, represents the difference in value between the positive and negative peaks of the wave. Of course, this is equal to twice the peak value: $E_{pk-pk} = 2\ E_{pk}$ for a sine wave.

1-12. Another useful value for the sine wave is the EFFECTIVE value. The effective value of a sine wave is the amount of current or voltage that produces the same heating effect as an equal amount of direct current or voltage. Since the heating effect (power) is proportional to the square of the current, or voltage, we can calculate the effective value by squaring the instantaneous values of all the points on the sine wave, taking the average of these values, and extracting the square root. The effective value is, thus, the root of the mean (average) square of these values. This value is known as the ROOT-MEAN-SQUARE, or RMS value. When we speak of household voltage as having the value of 110 volts, we mean that it has an effective or RMS value of 110 volts. Unless otherwise stated, AC voltage or current is expressed as the effective value.

1-13. Suppose we have a sine wave with a peak amplitude of 1 volt. The square root of the average of the squares of the values of this sine wave is .707. This means that a sine wave of voltage whose peak value is 1 volt will have the same heating effect as .707 volts of DC. To find the effective value of a sine wave, multiply .707 times the peak value:

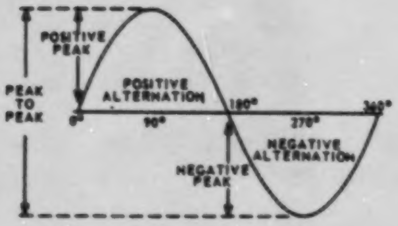

Figure 1-3. Sine Wave Labeling

$$E_{eff} = .707E_{pk}$$

1-14. For example, if a sine wave has a peak amplitude of 10 volts, the effective voltage is 7.07 volts (.707 x 10 = 7.07).

1-15. The reciprocal of .707 is 1.414. Therefore, if you know the effective value of a sine wave, you can find the peak value by multiplying the effective value by 1.414:

$$E_{pk} = 1.414\ E_{eff}$$

1-16. Another sine wave value that is important to know is the AVERAGE value. This is the average of the instantaneous values of all points in a SINGLE alternation.

1-17. Refer to figure 1-3; the AVERAGE height of a single alternation is .637 times the peak value. In other words, $E_{ave} = .637\ E_{pk}$. The relationship between the average, peak, and effective values is shown in the following formula:

$$E_{ave} = .637\ E_{pk} = .9\ E_{eff}$$

1-18. As you can see, average voltage is equal to .637 of the peak voltage and .9 of the effective voltage. The reciprocal of .9 is 1.11. Therefore, the effective voltage is 1/11 times the average voltage.

$$E_{eff} = 1.11\ E_{ave}$$

1-19. Now, let us identify some additional sine wave terms, using figure 1-4.

1-20. As stated before, alternating current periodically reverses direction. We call two consecutive alternations, one positive and one negative, a CYCLE. The positive and negative alternations are HALF-CYCLES. The positive half-cycle rises from zero to maximum positive and then returns to zero. The negative half-cycle rises from zero to a maximum negative value and then returns to zero.

1-21. The alternations of AC do not happen instantaneously. They take TIME. For example, household current takes one-sixtieth of a second for a single cycle. The term PERIOD is used to define the time of one cycle of alternating current. Another term having the same meaning as time and period is DURATION. Let us see how each of these terms could be used when speaking of household current. We could say, "The DURATION of one cycle is one-sixtieth of a second"; or "One cycle has a PERIOD of one-sixtieth of a second"; or "One-sixtieth of a second is the TIME of one cycle." As you can see, all three terms can be used in each of the statements without changing the meaning.

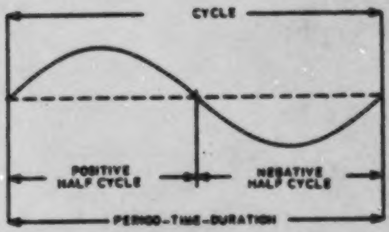

Figure 1-4. Sine Wave

1-22. Alternating currents have periods other than one-sixtieth of a second. The current commonly used in aircraft has a period of one four-hundredth of a second. This means that one cycle takes one four-hundredth of a second and in one second there are four hundred cycles. The difference in the number of cycles in one second between aircraft current and household current brings up a new term – FREQUENCY. The frequency of any AC is the number of cycles that occur in one second. This brings us to another term - HERTZ. HERTZ is a UNIT OF FREQUENCY EQUAL TO ONE CYCLE PER SECOND. Instead of saying sixty cycles per second, we will say sixty hertz. Hertz is abbreviated Hz.

1-23. As you can see in figure 1-5, there is a definite relationship between the period of an alternating current and the frequency of the current. Notice that sine wave B has a period that is one-half the period of sine wave A, and the frequency of B is twice the frequency of sine wave A. It is important to remember that, as the period of time for one cycle becomes shorter, the frequency increases or as frequency increases, the period of one cycle decreases.

1-24. In electronics, sixty hertz (60 Hz) and four hundred hertz (400 Hz) are relatively low frequencies. When we talk of frequencies

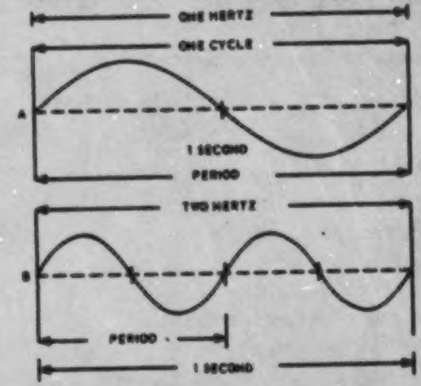

Figure 1-5. Frequency Comparison

in the thousands or millions, it becomes awkward and cumbersome to use cycles as a standard measuring term. Therefore, when we speak of frequencies in the thousands, we use the term KILOHERTZ (kHz); and when we speak of frequencies in the millions, we use the term MEGAHERTZ (MHz). You no doubt have heard these terms on radio and television when the announcer identifies the station. When you studied powers of 10, you learned that the term KILO means thousand and that the term MEGA stands for million. Therefore, kilohertz means a thousand hertz and megahertz means a million hertz.

1-25. When we speak of a frequency of 10 kilohertz, we mean that there are 10,000 cycles per second. When we speak of a frequency of 600 megahertz, we are speaking of 600,000,000 cycles per second.

1-26. Since the period of a cycle becomes smaller as the frequency increases, we not only need new terms for very high values, but we also need new terms for very small values. Therefore, we use the prefixes MILLI and MICRO when we talk of a thousandth or millionth part of something. When we talk of a thousandth of a second, we say MILLISECOND (ms). We use MICROSECOND (μs) when we talk of a millionth of a second.

1-27. Now, let us go back to the sine wave and take up a few more points. An AC sine wave is a pictorial presentation of alternating current. It shows the direction of current by raising above, and dropping below, the zero reference line. The current reverses direction at the zero reference line at the beginning of each half-cycle. There are two CURRENT REVERSALS in each cycle. We can find the number of current reversals in an AC signal by multiplying the frequency by two. A sixty-hertz current has one-hundred-twenty-current reversals per second (60 x 2 = 120).

1-28. Phase Relationship.

1-29. Sine waves are voltages or currents that vary with time. It is possible to have two sine waves that have the same frequency, but reach their positive peaks at different times.

1-30. Figure 1-6 shows three sine waves. Notice that wave A and wave B move together. That is, they start at zero, rise to maximum at ninety degrees, return to zero at one-hundred-eighty degrees and repeats the same action in the negative half-cycle. Because the two sine waves go through all parts of the cycle together, they are in-phase. The sine waves may represent voltage or current. The voltage may be in-phase or a current may be in-phase with a voltage.

1-31. An OUT-OF-PHASE relationship exists any time that the waves do not move together. This out-of-phase relationship can be seen by comparing sine wave A and sine wave C in figure 1-6. As you can see, the sine wave C is maximum negative when the sine wave A is zero (at the start of its positive half-cycle). Wave C reaches zero when wave A goes maximum positive and reaches maximum positive ninety degrees later when wave A is zero. When describing this relationship, we say that wave C LAGS wave A by ninety degrees. It is also said that wave A leads wave C by ninety degrees.

1-32. Deleted.

1-33. Deleted.

1-34. Frequency Classification.

1-35. A rainbow is produced when sun light is separated into many frequencies by individual rain drops. Some of these frequencies

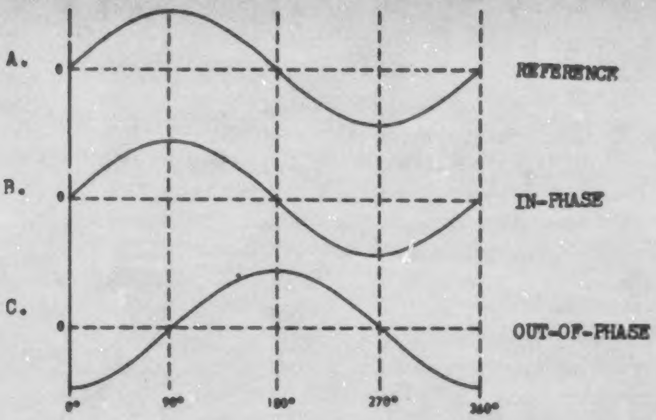

Figure 1-6. Phase Relationship

are seen as the colors - violet, blue, green, yellow, orange, and red. The frequencies immediately above the visible spectrum are called ultraviolet and the frequencies immediately below the visible spectrum are called infrared. Since all visible rays exist between the ultraviolet and infrared frequencies, we refer to the visible light frequencies as a group. That is, they differ from other frequencies in a special way. We find other frequencies arranged into groups in a similar manner. You have no doubt heard of x-rays, cosmic rays, alpha rays, beta rays, gamma rays, and microwaves. Figure 1-7 shows the range of frequencies making up the frequency spectrum.

1-36. Refer to figure 1-7 to see how the frequencies used in electronics are grouped. Notice that DIRECT CURRENT (DC) has zero frequency (no alternations). Frequencies between 0 Hz and about 2,500 Hz are classified as POWER FREQUENCIES. The frequencies between 20 Hz and 300 GHz are classified into two broad groups called AUDIO FREQUENCIES and RADIO FREQUENCIES. The audio frequency group includes all frequencies that, when converted to mechanical vibrations, can be detected by the human ear. The frequencies above the audio range, when converted to electrical vibrations, are classified as radio frequencies because they are used for radio-wave transmission.

1-37. POWER FREQUENCIES. Power frequencies range from 0 Hz (DC) to almost 3 kHz and overlap a portion of the audio frequency range. DC is used as the power source for electronic amplifiers. The most common AC power frequencies are 60 Hz and 400 Hz. Of course, these two frequencies are not

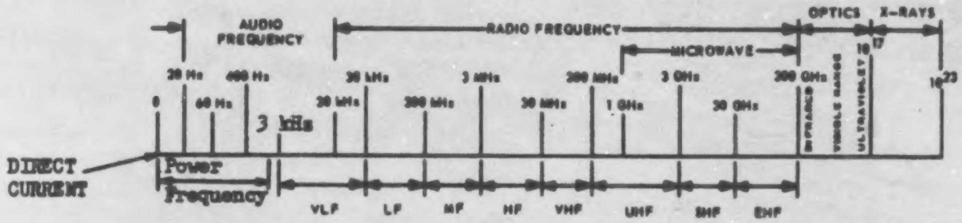

Figure 1-7. Frequency Spectrum

the only ones produced by power sources. In the United States 60 Hz is the common household power frequency. Many countries of the world use 50 Hz. Aircraft and ships use 400 Hz as a power frequency to save space and weight. Smaller components are used with the higher frequency.

1-38. AUDIO FREQUENCIES. For the time being, let us concentrate on the audio frequencies. These are the frequencies between 20 Hz and 20 kHz. We can hear these frequencies and we can distinguish between them. For example, if you hit two keys on a piano, you can detect the tone of each key. The tone with the higher pitch has the greater frequency. If we produce tones of higher and higher frequency, the pitch of the tones becomes higher and higher until we can no longer hear them. The exact point in the audio range of frequencies where tones can no longer be heard is not the same for all individuals. Therefore, the upper limit of the audio frequency range is an arbitrary figure of 20 kHz.

1-39. RADIO FREQUENCIES. The frequencies between 20 kHz and 300 GHz are classified as radio frequencies. Since different frequencies within this wide range produce different effects in transmission, they are subdivided into bands for convenience of study and reference. The bottom portion of figure 1-7 shows how the frequency spectrum is divided into bands.

1-40. Notice that the lower frequencies, those below 30 kHz, are classified in the VERY-LOW FREQUENCY (VLF) band. This band includes some of the audio frequencies. All of the bands have an upper limit which is ten times the value of their lower limit. The next band above the VLF is the LOW-FREQUENCY (LF) band which includes the frequencies between 30 kHz and 300 kHz. Frequencies between 300 kHz and 3 MHz are in the MEDIUM-FREQUENCY (MF) band. This is the band which includes the commercial radio broadcasting frequencies (535 kHz to 1650 kHz). The rest of the spectrum is considered high frequency and is divided into HIGH-FREQUENCY (HF), VERY-HIGH FREQUENCY (VHF), ULTRA-HIGH FREQUENCY (UHF), SUPER-HIGH FREQUENCY (SHF), and EXTREMELY-HIGH FREQUENCY (EHF) bands. You have no doubt heard of VHF and UHF in connection with television. Most airborne radars operate in the SHF range. The term MICROWAVE is loosely applied to frequencies above 1000 MHz.

1-41. Frequency Calculation.

1-42. You learned that the most common AC waveform is the sine wave. We defined frequency as the number of cycles which occur every second, so a wave which occurs sixty times every second is defined as a frequency of 60 hertz.

1-43. Wave motion is abundant in nature. You are familiar with waves on the surface of water. Sound consists of waves which can be transmitted through a physical medium. Earlier we spoke of light waves, and how they form a rainbow.

1-44. Many times when you were making up your bed, you flipped the end of the blanket to smooth out the wrinkles. You probably noticed that when you did this, you created a wave in the blanket that started at your fingers and moved down to the bed. If you cannot remember doing this, try it. Notice that you can control the wave by the arm movement you use. This is illustrated in figure 1-8. When the arm movement is slower, a longer wave is developed, as shown in the upper illustration. Notice in the lower illustration, when the arm movement is faster, a shorter wave is created. By comparing these two waves, you can see that the longer wave covers more distance than the shorter one. The top wave obviously was the greater length, or, using a new term: its WAVELENGTH is longer. Thus, you can see that wavelength means the actual physical length of the wave.

1-45. At this point, distinguish between WAVELENGTH and WAVE AMPLITUDE. A sound, for example, may be a fixed tone (wavelength) but it may be loud or soft (amplitude).

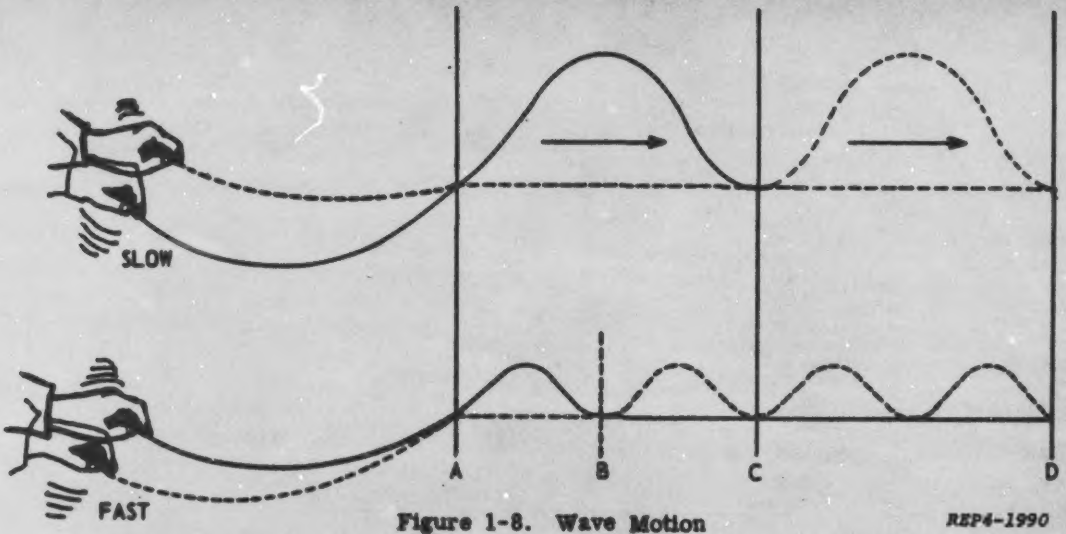

Figure 1-8. Wave Motion

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1-46. Now, let's look at wavelength from another point of view. Wavelength can also mean the distance that the front part of the wave will travel beyond a certain point by the time the end of the wave reaches this point. As you can see in figure 1-8, if we use C as our reference point, the leading part of the top wave will be at point D when the trailing edge of the wave reaches the reference point. This is represented by the dotted line and represents one wavelength.

1-47. If the elements of the upper and lower waves of figure 1-8 travel at the same speed, then two waves of the lower illustration will pass point C in the same time that it takes one wave in the upper illustration to pass the same point. Since wavelength is the distance traveled during the period of one wave, the wavelength of the lower waves is only one-half of the wavelength of the upper wave. As you can see, the WAVELENGTH involves two factors: speed and frequency. Speed is the rate of movement, or velocity. Frequency is based on how often the waves occur in a given period of time. In the electronics frequency spectrum, the time reference for frequency is one second.

1-48. In electronics, the term WAVELENGTH is defined as the distance an electromagnetic wave travels in the time of one cycle. Electromagnetic waves are radio waves which travel through space. Electromagnetic waves move away from a source at a constant velocity of 300 MILLION METERS PER SECOND. The wavelength is measured in meters and the period of the wave in seconds. Let's see how these units are placed in a formula.

1-49. First, the symbol for the wavelength is the Greek letter lambda (λ). Lambda is equal to velocity (V) times the time (t) of one cycle, and we have the formula:

$$\lambda = Vt$$

1-50. Since the velocity of electromagnetic waves through space is 300 million meters per second, we substitute 300,000,000 for V:

$$\lambda = 300{,}000{,}000 \times t$$

$$\lambda = 300 \times 10^{6} \times t$$

The formula for wavelength gives the number of meters that a wave will travel during the time of one cycle. If the frequency of the wave is one Hz, the wave will travel 300×10^{6} meters in one cycle.

1-51. Let's take a moment to consider the relationship of time required for one cycle and frequency. The time of one cycle varies inversely with the frequency. A frequency of one thousand Hz will require one thousandth of a second for one cycle. In other words, if we have one thousand cycles in one second, the time of one cycle is one thousandth of a second. We discussed this with 60 hertz, where the time of one cycle is one-sixtieth of a second. We can thus derive a formula:

$$f = \frac{1}{t}$$

where f is the frequency in Hz and t is the time in seconds required for one cycle of that frequency. We can solve this equation for t to find that:

$$t = \frac{1}{f}$$

1-52. Now, since the factors are the same, we can substitute $\frac{1}{f}$ for t in the wavelength formula:

$$\lambda = 300 \times 10^6 \times \frac{1}{f} \text{ or simply: } = \frac{300 \times 10^6}{f}$$

1-53. Now, we'll work a problem to see how to use this formula. Given a frequency of 3000 hertz solve for wavelength. Substituting in the formula, we have:

$$\lambda = \frac{(300 \times 10^6)}{3000} = \frac{(300 \times 10^6)}{(3 \times 10^3)} =$$

$$\frac{(300 \times 10^6) \times 10^{-3}}{3} = 100 \times 10^3$$

This gives us 100,000 meters or 100 kilometers as the wavelength.

1-54. If the frequency of an AC is 30,000 MHz, we would find the wavelength by substituting in the formula as follows:

$$\lambda = \frac{(300 \times 10^6)}{(30{,}000 \times 10^6)} = \frac{(3 \times 10^8)}{(3 \times 10^{10})} = 1 \times 10^{-2}$$

This gives us .01 meter as the wavelength.

1-55. We can use the formula: $\lambda = \frac{300 \times 10^6}{f}$ to find the frequency of an AC if we know its wavelength. We must first convert the formula statement by solving for f. The formula becomes: $f = \frac{300 \times 10^6}{\lambda}$

1-56. To find the frequency of an AC whose wavelength is 1000 meters, we substitute this value in the formula and get:

$$f = \frac{(300 \times 10^6)}{1000} = \frac{(300 \times 10^6)}{(1 \times 10^3)} = 300 \times 10^3 \text{ Hz}$$

1-57. Let's do another. Suppose we want to know the frequency of an AC whose wavelength is .05 meters. Now, substituting in the formula, we get:

$$f = \frac{300 \times 10^6}{.05} = \frac{300 \times 10^6}{5 \times 10^{-2}} = 60 \times 10^8 \text{ Hz}$$

This gives us a frequency of 6,000,000,000 Hz. This is the same as writing 6000 MHz or 6 gigahertz (6 GHz).

1-58. There is a definite relationship between wavelength, frequency, and time period of a cycle. You can find the time period if you know either the wavelength or the frequency. Figure 1-9 shows the relationship of these units of measure.

1-59. As you can see, figure 1-9 shows an AC with a frequency of five Hz. The period of one cycle is one-fifth of a second. Notice that the relationship of the wavelength to the distance traveled in one second is the same as the relationship of the period to one second.

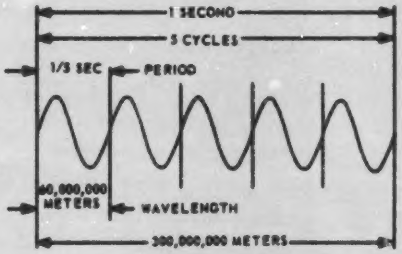

Figure 1-9. Relationship of Frequency, Wavelength, and Period

1-60. When frequency is high, you will find it simpler to express frequency, period, and wavelength using standard prefixes. As you know, millions of cycles per second are expressed as MHz. When the frequency is in megahertz (MHz), the time for one cycle is in millionths of a second, expressed as microseconds (µs).

1-61. Let's use this fact to find the period of an AC whose frequency is 20 MHz. Substituting, we have:

$$t = \frac{1}{f}$$

$$t_{\mu s} = \frac{1}{20\ \text{MHz}} = \frac{1}{20} = .05\ \mu s$$

1-62. This same principle can be used in solving for f in terms of t in the formula:

$$f = \frac{1}{t}$$

1-63. When the period is in microseconds (µs), the frequency is in megahertz (MHz).

1-64. Suppose you want to know the frequency of an AC whose period is fifty microseconds. You have:

$$f_{\text{MHz}} = \frac{1}{50\ \mu s} = \frac{1}{50} = .02\ \text{MHz}$$

This value can also be expressed as 20 kHz.

1-65. Notice that in the above example we expressed 50 microseconds as 50, and obtained 0.02. By using megahertz and microseconds in your calculations, you can save time and eliminate the excessive uses of zero. You can also use:

$$f_{\text{kHz}} = \frac{1}{t_{\text{ms}}}$$

and

$$t_{\text{ms}} = \frac{1}{f_{\text{kHz}}}$$

1-66. The important thing to remember from this lesson is that if either the wavelength, frequency, or period of an AC is known, you can find the other two values. If either the wavelength or period is known, you can find the frequency by dividing the wavelength into three hundred million or the period into one second. If the frequency is known, you can find the wavelength by dividing three hundred million by the frequency or your can find the period by dividing one second by the frequency. If you know the wavelength, you can find the period by dividing the wavelength by three hundred million.

NOTES

Chapter 2

CAPACITORS AND CAPACITIVE REACTANCE

2-1. This chapter introduces CAPACITANCE, which opposes a change in voltage. Like resistance, capacitance is a useful property of electronic circuits. Capacitance is present anytime two conductors are separated by an insulator. Thus it is possible for a circuit to have random or stray capacitance between its components and their wiring. This stray capacitance, called DISTRIBUTED CAPACITANCE, is discussed in later lessons. In this lesson, we will discuss LUMPED CAPACITANCE and the elements that affect it. Lumped capacitance is defined as a concentration of capacitance at a given point in a circuit.

2-2. The Capacitor.

2-3. A capacitor is a lumped capacitance. It consists of two conducting surfaces, called plates, which are separated by a nonconductor (insulator) called the dielectric.

2-4. The dielectric between the two plates may be vacuum, air, waxed paper, ceramic, glass, or any other nonconducting (insulating) material through which electrons will not easily pass.

2-5. Figure 2-1A shows the construction of a capacitor. Figure 2-1B shows the schematic symbol. This symbol represents the two plates with their connecting leads and the dielectric. The connecting leads are represented by the two horizontal lines, the plates by the two dark vertical lines (one of which is curved), and the dielectric by the space separating the two dark lines.

2-6. A capacitor stores energy between its plates. To understand how this energy is stored and what happens within the capacitor, we use the principles of electrostatics.

2-7. The Electrostatic Field. You already know that bodies having unlike charges attract each other and bodies having like charges repel each other. A body that is deficient in electrons is positively charged, while a body that has an excess of electrons is negatively charged. Each charged body has an electrostatic field and will exert a force of repulsion or attraction when placed near another charged body.

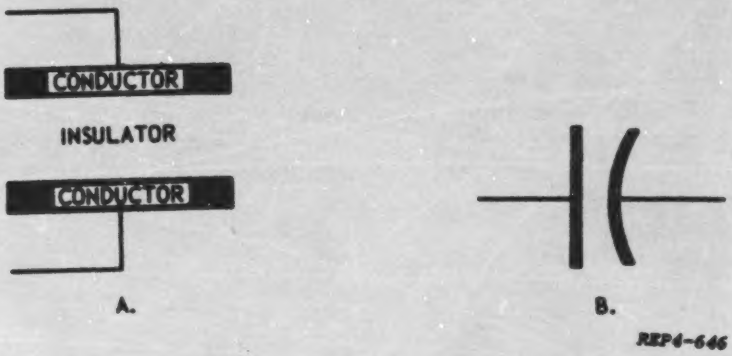

Figure 2-1. Capacitor Pictorial and Schematic Symbol

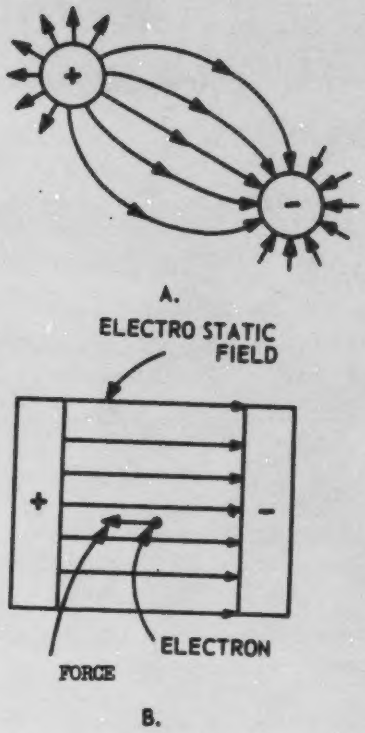

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Figure 2-2. Electrostatic Fields

2-8. The electrostatic lines of force that represent the static field, as shown in figure 2-2A, extend from the positively charged body to the negatively charged body. The closer the charged bodies are to each other the stronger the force is between them. The farther apart they move, the weaker the force becomes. The strength of this force of repulsion or attraction is inversely proportional to the distance between the charged bodies.

2-9. The illustration in figure 2-2B shows two charged metal plates, one negative, the other positive, and the electrostatic field between them. The field is represented by the arrows and extends in the direction shown by the arrows. If an electron is placed in the center of the electrostatic field, it would be repelled by the negative plate. Why? Because an electron carries a negative charge and like charges repel each other. On the other hand, it would be attracted by the positive plate. Therefore, a force is applied to an electron placed in an electrostatic field in a direction opposite to the direction of the electrostatic field. This force is the energy stored in the electrostatic field.

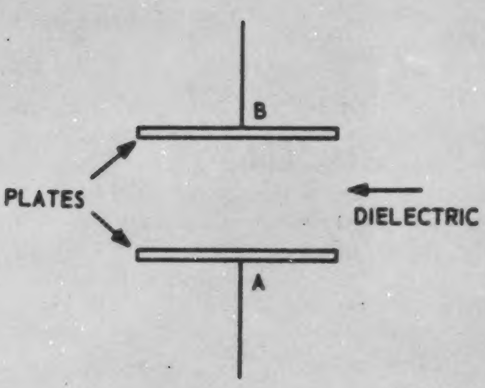

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Figure 2-3. Uncharged Capacitor

2-10. Figure 2-3 shows a capacitor in an uncharged condition. No electrostatic field exists between the two plates of the capacitor. As there is no charge on the plates, the atoms that make up the plates are in their normal state. By this we mean the atoms have neither gained nor lost electrons. For this discussion assume the dielectric is vacuum which has no atoms.

2-11. In figure 2-4, we apply a voltage to the capacitor and charge it. The positive post of the battery has a deficiency of electrons and the negative post an excess of electrons. Prior to the closing of the switch in figure 2-4 there was no way for the negatively charged post to rid itself of its excess

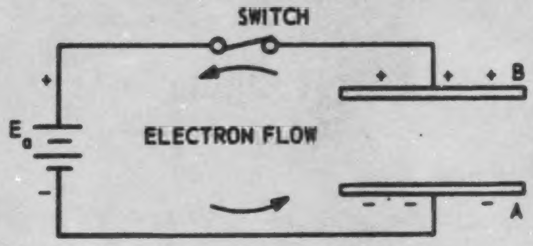

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Figure 2-4. Capacitor Charging

electrons. As well, there was no way for the positively charged post to gain electrons.

2-12. At the instant the switch is closed, two actions occur at the same time. One is that the excess electrons in the negative post of the battery move toward Plate A of the capacitor. The other action is that electrons from Plate B move toward the positive post of the battery. The movement of electrons is caused by the electrostatic forces of the charged posts of the battery. These forces repel electrons from the negative post down the conductor toward Plate A and attract electrons out of the conductor from Plate B. As Plate A and its conductor are now part of the negative post electrically, the charge is distributing itself over the new area. This is also the case with the positive post, Plate B, and the other conductor.

2-13. At the first instant there is maximum movement of electrons (current flow) in the two conductors. Why? Neither plate of the capacitor is charged, thus there is no static charge to oppose the movement of electrons to and from the plates. There is no difference in potential between the plates and no voltage across the capacitor. With maximum current flow and no voltage across the capacitor, the capacitor is EFFECTIVELY a short. Actually there is no current flow through the capacitor, but because electrons are leaving and entering the battery posts there is an appearance of current flow.

2-14. As electrons reach Plate A, it begins to receive a negative charge. At the same time Plate B looses electrons and begins to receive a positive charge. For every electron that Plate A gains, Plate B loses an electron. Since there is a vacuum between the two plates, the gained electrons on Plate A cannot cross to Plate B.

2-15. As there is now a charge on each of the capacitor's plates, there is a difference of potential between the plates. The capacitor now has a voltage across it.

2-16. The voltage across the capacitor opposes the movement of electrons from the battery. Thus, as the capacitor charges, the movement of electrons from the battery becomes steadily less.

2-17. When the charges on the capacitor's plates equal the charges on the battery's posts, the capacitor is fully CHARGED. All electron movement stops and the difference in potential across the capacitor is equal to the applied voltage (the voltage of the battery). Thus, once the capacitor is charged, it blocks the flow of DC and becomes an EFFECTIVE open.

2-18. Summarizing then; when voltage is applied to a capacitor, it is at the first instant an EFFECTIVE short with maximum current flow and no voltage across the capacitor. As the capacitor charges, current flow steadily decreases and the voltage across the capacitor steadily increases. When the capacitor is fully CHARGED, current stops and the voltage across the capacitor equals the applied voltage.

2-19. In figure 2-5, we opened the switch after the capacitor was fully charged. There is no way for Plate A of the capacitor to get rid of its excess electrons or for Plate B to gain electrons. Thus, the capacitor remains fully charged. We have energy stored in the electrostatic field of the capacitor. In effect, the capacitor is like a battery with a voltage equal to that of the battery that charged it.

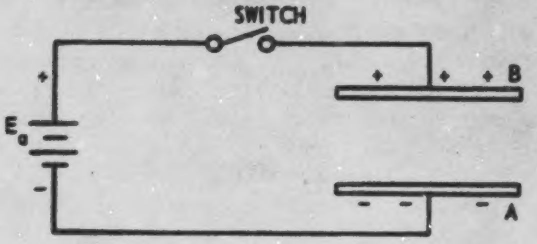

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Figure 2-5. Charged Capacitor

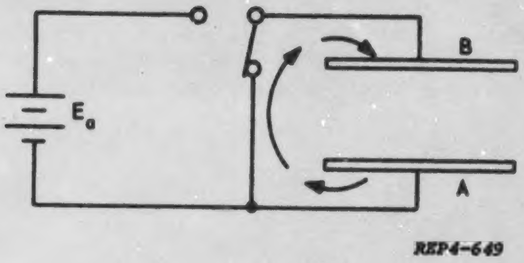

Figure 2-6. Capacitor Discharging

2-20. By altering the circuit (as shown in figure 2-6), a way is provided that allows the excess electrons in Plate A to move to Plate B which has a deficiency of electrons. Since the two charged plates are now connected by a conductor they will neutralize themselves. Specifically Plate A will give up its excess electrons to Plate B and both plates will lose their charge. Remember, the electrons gained by Plate A were equal in number to the electrons lost by Plate B. This process of neutralizing the charged plates of the capacitor is known as DISCHARGE. When the two plates are neutralized, the capacitor is fully DISCHARGED. A word of caution: Because a capacitor stores and retains energy in its electrostatic field NEVER work with a capacitor until you have fully discharged it.

2-21. What happens when the dielectric is not a vacuum? Figure 2-7 shows another capacitor in an uncharged condition. In this capacitor we are using a dielectric other than vacuum. The atoms that make up the dielectric are in their normal or neutral state. By this we mean that the electrons of each atom are revolving around their nucleus in normal orbital paths. Figure 2-7 shows only three atoms (greatly enlarged) of the millions that make up the dielectric material. The plates are uncharged and NO electrostatic field exists.

2-22. In figure 2-8, we apply a voltage to the capacitor. At the first instance the switch is closed there is maximum current flow and no voltage across the capacitor. The capacitor is an EFFECTIVE short.

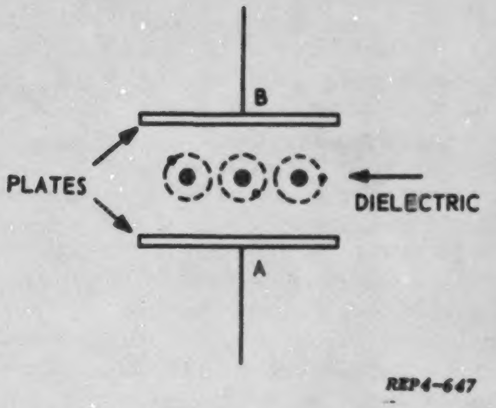

Figure 2-7. Uncharged Capacitor with Dielectric

2-23. Not only do the capacitor plates charge, but as the negative charge builds up on Plate A, due to gained electrons, it repels the electrons in the dielectric atoms. This causes the orbits of the electrons to become distorted as shown in figure 2-8. Further distortion is caused by the attraction of the positive charge on Plate B. This distortion of the electron orbits is known as orbital stress. Orbital stress stores energy much in the same manner as a stretched rubber band. As the charges on the capacitor plates steadily increases, the orbital stress on the electrons of the dielectric atoms steadily increases. Thus, this capacitor stores energy not only in the electrostatic charges on its plates, but also in the

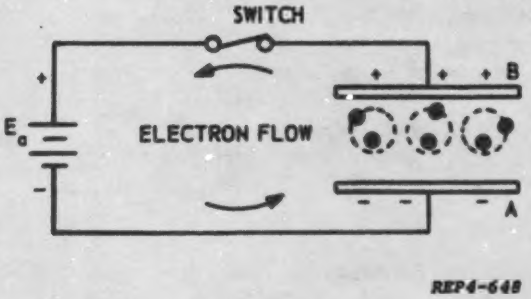

Figure 2-8. Orbital Stress

Table 2-1

DIELECTRIC FACTORS

DIELECTRIC MATERIAL	DIELECTRIC CONSTANT (k)	DIELECTRIC STRENGTH (volts per .001 inch)
AIR	1.0	80
FIBER	6.5	50
BAKELITE	6.0	500
GLASS	4.2	200
MICA	6.0	2000
CASTOR OIL	4.7	380
PAPER		
(1) beeswaxed	3.1	1800
(2) paraffined	2.2	1200

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This rating is determined by the electrical strength of the dielectric material. The dielectric strength tells you how much voltage may be applied to a given thickness of dielectric material. Every material (even an insulator) will conduct current if a sufficiently high voltage is applied to it. This voltage is called the breakdown voltage. The working voltage rating of a capacitor refers to the maximum DC value or maximum AC value of voltage that can be applied to the capacitor continuously. A capacitor marked 600 WVDC or 600 VDC should withstand the continuous application of 600 VDC or 600 V PEAK AC without damage to the capacitor.

2-40. Table 2-1 gives the dielectric strength of some dielectric materials that are one thousandth of an inch thick. Note that the dielectric constant and dielectric strength do not directly correlate. For example the dielectric constant for both mica and bakelite is six but their dielectric strengths are different. For mica it is 2000 and for bakelite it is 500. Therefore, increasing the capacitance of a capacitor by using a dielectric with a larger dielectric constant will not always increase the capacitor's working voltage rating.

2-41. Total Capacitance.

2-42. To determine total capacitance in a circuit, you must follow the rules for calculating the capacitance of capacitors connected in series, parallel, or series-parallel.

2-43. **Series.** To understand how total capacitance is computed in a series capacitive circuit, it is necessary to apply what we have learned about the capacitor. In figure 2-11A, the circuit has two capacitors connected in series. Plate B of capacitor C1 and Plate C of capacitor C2 are connected together by a conductor. As both of these plates are conductors; plate B of C1, plate C of C2 and the conductor combine to form one conductor. Since any point along a conductor is electrically the same, the circuit can be redrawn as shown in figure 3-11B. Both capacitors become EFFECTIVELY one capacitor with plate A of C1 and Plate D of C2 as its plates and the combined dielectrics of both C1 and C2 as its dielectric. Since increasing the dielectric thickness of a

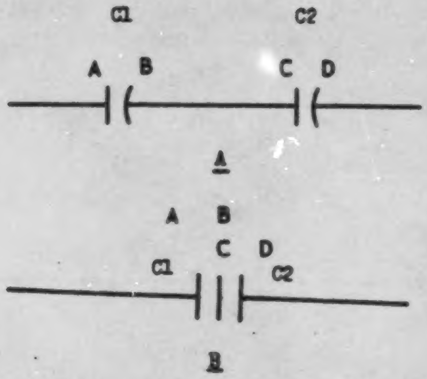

Figure 2-11. Series Equivalent Circuit

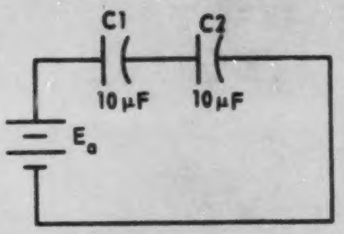

Figure 2-12. Series Capacitors

capacitor decreases its capacitance, the total capacitance of the two series capacitors will be less than the capacitance value of either capacitor.

2-44. The formulas for total capacitance in a series circuit are:

$$C_t = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \text{etc.}}$$ For any number of capacitors.

$$C_t = \frac{C}{N}$$ For any number of capacitors of equal value where C equals the value of one capacitor and N equals the number of capacitors.

$$C_t = \frac{C1 \times C2}{C1 + C2}$$ For two capacitors.

2-45. Figure 2-12 shows a series capacitive circuit. In solving for total capacitance in this circuit, we will show two methods, each using a different formula.

Method A: $$C_t = \frac{C}{N}$$

$$C_t = \frac{10\,\mu F}{2}$$

$$C_t = 5\,\mu F$$

Method B: $$C_t = \frac{C1 \times C2}{C1 + C2}$$

$$C_t = \frac{10\,\mu F \times 10\,\mu F}{10\,\mu F + 10\,\mu F}$$

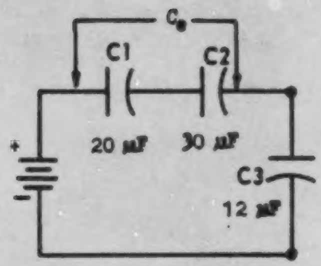

Figure 2-13. Three Component Series Circuit

$$C_t = \frac{100\,pF}{20\,\mu F}$$

$$C_t = 5\,\mu F$$

2-46. Figure 2-13 shows another series circuit. To solve for total capacitance in this circuit, two methods will be used again. One using a single formula, the other using two formulas.

Method A: $$C_t = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

$$C_t = \frac{1}{\frac{1}{20\,\mu F} + \frac{1}{30\,\mu F} + \frac{1}{12\,\mu F}}$$

$$C_t = \frac{1}{\frac{3}{60\,\mu F} + \frac{2}{60\,\mu F} + \frac{5}{60\,\mu F}}$$

$$C_t = \frac{1}{\frac{10}{60\,\mu F}}$$

$$C_t = \frac{60\,\mu F}{10}$$

$$C_t = 6\,\mu F$$

Method B: First find the value of C_e:

$$C_e = \frac{C1 \times C2}{C1 + C2}$$

$$C_e = \frac{20\,\mu F \times 30\,\mu F}{20\,\mu F + 30\,\mu F}$$

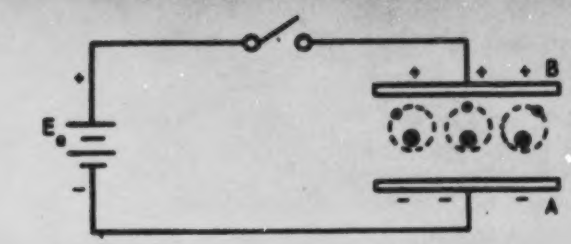

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Figure 2-9. Stored Charge

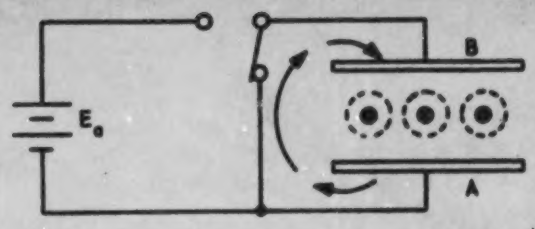

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Figure 2-10. Discharge Path

orbital stress on the electrons of its dielectric atoms. Using a dielectric (insulator) other than a vacuum increases the amount of energy stored. Air is one exception. Although air does have atoms, it does not increase the ability of the capacitor to store energy.

2-24. When the capacitor is fully charged the orbital stress on the electrons of the dielectric atoms is maximum. Current flow has stopped and the difference in potential across the capacitor is equal to the applied voltage.

2-25. Thus, the charging action of this capacitor is the same as the capacitor with a vacuum dielectric. However, a capacitor with a dielectric other than a vacuum or air will store more electrons.

2-26. In figure 2-9, we open the switch in the circuit after the capacitor is fully charged. As there is no way for the charges on the capacitor plates to neutralize themselves, the capacitor remains fully charged. This results in the orbital stress remaining at its greatest point as the orbital stress is caused by the charges on the capacitor plates.

2-27. A path to discharge the capacitor is provided in figure 2-10. The excess electrons move from Plate A to Plate B, neutralizing the charges on the plate. This discharge current will be greater than for a vacuum dielectric due to the extra energy stored as orbital stress.

2-28. Summarizing: Regardless of the type of dielectric, current does not flow through it. (There is, of course, some extremely minute amount of electron movement through the dielectric but it is so small as to be insignificant. If this leakage of electrons becomes significant, the the capacitor is bad.) At the first instant, a capacitor is an EFFECTIVE short with maximum current flow in the circuit and no voltage across the capacitor. During charge of the capacitor, current flow in the circuit steadily decreases and voltage across the capacitor steadily increases. A fully charged capacitor is an EFFECTIVE open with no current flow in the circuit and applied voltage across the capacitor. By changing the type of dielectric, the ability of the capacitor to store electrons may be increased.

2-29. Capacitance.

2-30. Knowing what a capacitor is and how it stores energy, we now turn to the question "How do we measure the ability of a capacitor to store energy and what do we call this measure?"

2-31. Capacitance may be defined as the measure of the ability of two conducting surfaces, that are separated by a nonconductor, to store electrical energy. Therefore, the measure of the ability of a capacitor to store electrical energy is the capacitance of the capacitor. The symbol for capacitance is C.

2-32. The unit of measure for capacitance is the FARAD. A Farad is defined as the ability of a capacitor to store one coulomb (6.28×10^{18} electrons) with a difference of potential of one volt across the capacitor.

The symbol for a farad is F. Most capacitors in common use are much smaller in value. Generally their capacitance is measured in millionths of a farad. A millionth of a farad is called a microfarad (1×10^{-6} farads) and its symbol is μF. A million-millionth of a farad is called a picofarad (1×10^{-12} farads) and its symbol is pF.

2-33. The amount of charge stored in a capacitor is directly proportional to the strength of the applied voltage and the CAPACITY of the capacitor. This can be expressed as $Q = CE$ where Q is the charge and E is the applied voltage. When this formula is transposed, the value of capacitance can be found by the formula $C = \frac{Q}{E}$. Or in other words the capacitance (capacity) of a capacitor will determine the ratio of the amount of charge to the applied voltage.

2-34. Capacitance is determined by the physical factors of a capacitor. These factors are the area of the plates, the type of dielectric material, and the dielectric thickness or distance between the plates. Capacitance is equal to the ratio of the dielectric constant of the dielectric material and plate area to the dielectric thickness. This can be shown by the formula: $C = \frac{kA}{d}$

where: k is the dielectric constant.

A is the plate area.

d is the dielectric thickness.

C is the capacitance.

This formula must be multiplied by another constant to satisfy engineering requirements. However, the additional constant is not required for this course.

2-35. The capacitance of a capacitor is directly proportional to its plate area. As plate area increases, capacitance increases or as plate area decreases, capacitance decreases. Why? The number of atoms in a conductor is dependent on the size of the conductor. In turn, the number of atoms determines the number of free electrons in the conductor that are available to enter and leave the plates. As the number of free electrons increase, the plates will accept a larger charge. When free electrons decrease in number, the plate will accept a smaller charge.

2-36. The capacitance of a capacitor is directly proportional to the dielectric constant. As the dielectric constant increases, capacitance increases. If the dielectric constant decreases, capacitance decreases. When we discussed how a capacitor stores energy, you learned that by using a dielectric other than vacuum the capacitor could store more energy. Different dielectric materials present different quantities of electrons to the electrostatic field. This means that there are different amounts of energy stored as orbital stress. Vacuum is the standard for the dielectric constant and is assigned a numerical value of one. All other dielectric materials are compared with a vacuum dielectric and assigned a numerical value for their dielectric constant. This numerical value indicates by how much the dielectric material increases the capacitor's ability to store energy when compared to a vacuum dielectric.

2-37. Table 2-1 gives the dielectric constant value of some common materials. Looking at the table, you will see that the use of air instead of vacuum as the dielectric does NOT increase the capacitor's ability to store energy.

2-38. The capacitance of a capacitor is inversely proportional to the dielectric thickness or distance between the plates. When the distance between the plates increases, the forces of attraction and repulsion (created by charged plates) decrease. This causes the amount of charge to decrease. As distance between the plate decreases, the forces of attraction and repulsion increase and the amount of charge increases. Thus, as dielectric thickness increases, capacitance decreases. As dielectric thickness decreases, capacitance increases.

2-39. In addition to its capacitance value, every capacitor has a working voltage rating.

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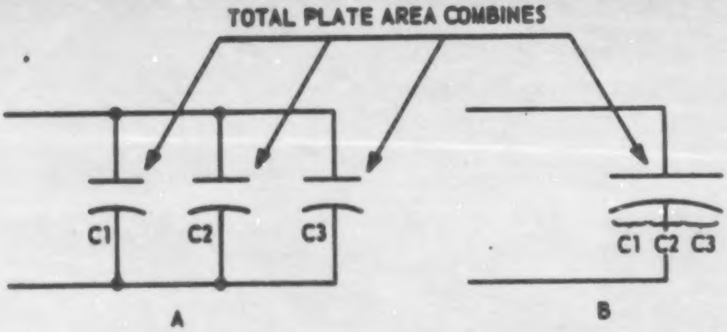


REP4-652

Figure 2-14. Parallel Equivalent Circuit

$$C_e = \frac{600\ pF}{50\ \mu F}$$

$$C_e = 12\ \mu F$$

Now use C_e and C3 to determine C_t:

$$C_t = \frac{C}{N}$$

$$C_t = \frac{12\ \mu F}{2}$$

$$C_t = 6\ \mu F$$

2-47. **Parallel.** To determine how we compute total capacitance for a parallel capacitive circuit, we again apply what we have learned about the capacitor. In figure 2-14A, there are three capacitors connected in parallel. The top plate of all three capacitors are connected together by conductors. As the plates are also conductors, the three plates and the conductors combine to form one conductor. The bottom plate of all three capacitors are connected together and combined to form one conductor. Since any point along a conductor is electrically the same, the circuit can be redrawn as shown in figure 2-14B. The three capacitors become EFFECTIVELY one capacitor. Notice that the thickness of the dielectric material remains the same. All we have changed is the effective area of the capacitor plates. As plate surface area and capacitance are directly proportional, the total capacitance will be the sum of the capacitance values for the three capacitors. Thus total capacitance for a parallel capacitive circuit can be found by using the formula; C_t = C1 + C2 + C3 + etc.

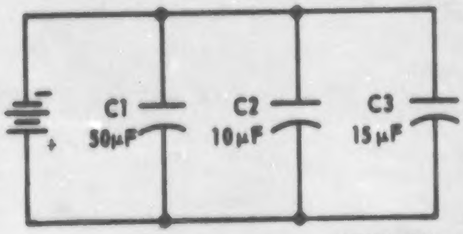
2-49. Figure 2-15 shows a parallel capacitive circuit. To solve for total capacitance, simply add the capacitance values of the capacitors as shown.

$$C_t = C1 + C2 + C3$$

$$= 50\ \mu F + 10\ \mu F + 15\ \mu F$$

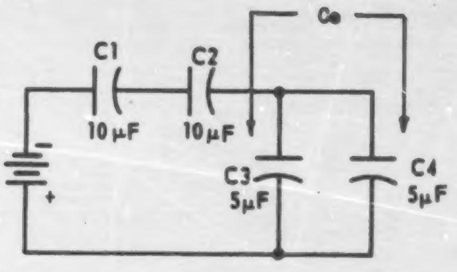
$$= 75\ \mu F$$

2-50. **Series-Parallel.** Now that you know how to find total capacitance both in series and parallel circuits, these knowledges can be combined to solve for C_t in series-parallel circuits. You should study the circuit to determine which part of the circuit should be solved first. Normally the parallel part would be solved first.



REP4-561

Figure 2-15. Three Component Parallel Circuit



REP4-653

Figure 2-16. Series-Parallel Circuit

2-51. Figure 2-16 shows a series-parallel circuit. To solve for total capacitance, use the following procedure:

First solve for the equivalent capacitance of the parallel network.

$$C_e = C3 + C4$$

$$= 5\ \mu f + 5\ \mu F$$

$$= 10\ \mu F$$

Now solve for C_t. Since C_e, C1, and C2 are each equal to 10 µF, use the formula:

$$C_t = \frac{C}{N}$$

$$= \frac{10\ \mu F}{3}$$

$$= 3.3\ \mu F$$

2-52. Figure 2-17 shows another series-parallel circuit. To solve for total capacitance in this circuit, first solve for the equivalent capacitance of the parallel network.

$$C_{e1} = C3 + C4$$

$$= 8\ \mu F + 4\ \mu F$$

$$= 12\ \mu F$$

Now combine C1 and C2. As C1 and C2 are equal to each other, solve for their equivalent capacitance using the formula:

$$C_{e2} = \frac{C}{N}$$

$$= \frac{8\ \mu F}{2}$$

$$= 4\ \mu F$$

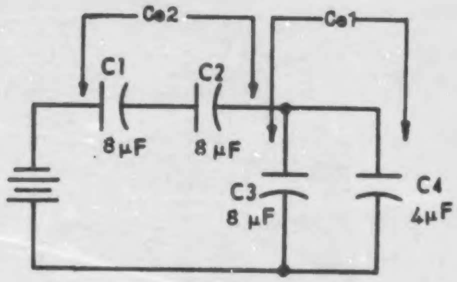


Figure 2-17. Equivalent Capacitance

$$C_t = \frac{C_{e1} \times C_{e2}}{C_{e1} + C_{e2}}$$

$$= \frac{12\ \mu F \times 4\ \mu F}{12\ \mu F + 4\ \mu F}$$

$$= \frac{48 \times 10^{-12}}{16 + 10^{-6}}$$

$$= 3 \times 10^{-6}\ \text{Farads}$$

$$= 3\ \mu F$$

2-53. Figure 2-18 shows a final example of a series-parallel circuit. Solve for total capacitance.

In this circuit one of the branches in the parallel network has two capacitors in series. Therefore, the equivalent capacitance of C4 and C5 is solved first.

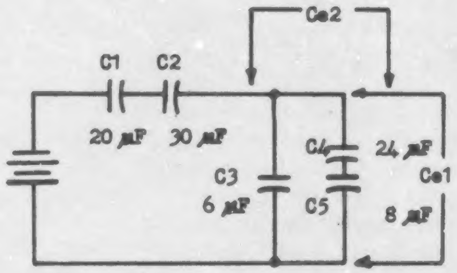
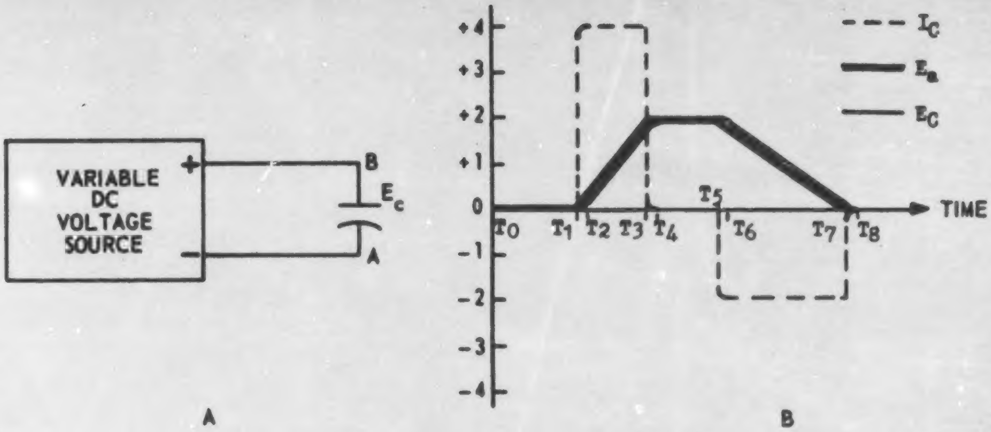


Figure 2-18. Complex Series-Parallel Circuit



REP4-654

Figure 2-19. DC Voltage-Current Relationships

$$C_{e1} = \frac{C4 \times C5}{C4 + C5}$$

$$= \frac{(24 \times 10^{-6}) \times (8 \times 10^{-6})}{(24 \times 10^{-6}) + (8 \times 10^{-6})}$$

$$= \frac{192 \times 10^{-12}}{32 \times 10^{-6}}$$

$$= 6 \times 10^{-6} \text{ farads}$$

$$= 6\,\mu F$$

Now solve for the equivalent capacitance of the parallel branch.

$$C_{e2} = C3 + C_{e1}$$

$$C_{e2} = 6\,\mu F + 6\,\mu F$$

$$C_{e2} = 12\,\mu F$$

Next determine total capacitance by using the formula:

$$C_t = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C_{e2}}}$$

$$= \frac{1}{\frac{1}{20\,\mu F} + \frac{1}{30\,\mu F} + \frac{1}{12\,\mu F}}$$

$$= \frac{1}{\frac{3}{60\,\mu F} + \frac{2}{60\,\mu F} + \frac{5}{60\,\mu F}}$$

$$= \frac{60\,\mu F}{10}$$

$$= 6\,\mu F$$

2-54. Up to this point, the capacitor has had only a DC voltage applied to it. In the material that follows, an AC voltage will be applied to the capacitor. When a constant DC voltage is applied to a capacitor, the capacitor charges to the value of applied voltage and current flow in the circuit stops. However, when an AC voltage is applied to a capacitor, current will not only continue to flow in the circuit but change direction as well. Keep in mind that current does NOT actually flow through a capacitor. Current APPEARS to flow through it because electrons are entering one plate and leaving the other plate.

2-55. In determining how it is possible to have current in an AC capacitive circuit, a variable DC voltage source will be used to begin the explanation. Figure 2-19A shows a capacitor connected to a variable DC voltage source. The graph in figure 2-19B shows the amplitude relationship that exists between applied voltage and the voltage across the capacitor with respect to time. It also shows the current charging and discharging the capacitor and the direction in which it flows.

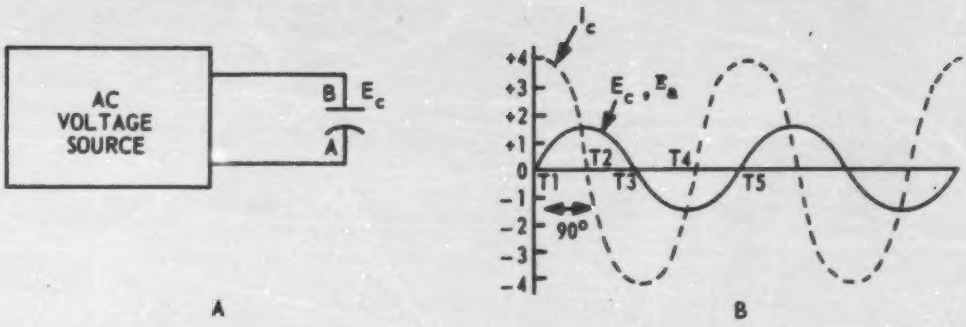


Figure 2-20. AC Voltage-Current Relationships

2-56. Between times T0 and T1 of figure 2-19B, both voltage and current are zero. At time T1, voltage (E_a) starts increasing at a steady rate to time T3. From T1 to T2 current increases from zero to maximum current (I_C) and a charge (voltage E_C) begins to build up on the capacitor's plates. However, the current remains at maximum value even with the charge being developed on the capacitor plates. The reason for this is that E_a is constantly increasing at a steady rate. The capacitor continually sees a new voltage that it must charge up to. At time T3 the applied voltage reaches maximum value and remains there until time T5. Between time T3 and time T4 the capacitor completes its charge to E_a and current decreases from its maximum value to zero. Thus at time T4, E_a and E_C are equal and current is zero. E_a, E_C, and I_C remain at these values until time T5. NOTE: The time period (T1 to T2) between the time voltage is applied to the capacitor and the time the capacitor starts to charge has been greatly expanded.

2-57. At time T5, applied voltage (E_a) begins to decrease at a steady rate from time T5 to time T7. From T5 to T6 the discharge current increases from zero to maximum in a direction that is now opposite to what it was when the capacitor was charging. At time T6, the capacitor voltage (E_C) starts to decrease at a steady rate. The discharge current (I_C) remains at a constant value until time T7, even though the capacitor voltage is decreasing. Why? Because the applied voltage (E_a) is constantly decreasing at a steady rate, the capacitor continually sees a new voltage it must discharge to. After the applied voltage reaches zero volts at time T7, the capacitor completes its discharge to zero volts at time T8. During the time from T7 to T8, I_C decreases from its maximum value to zero. At time T8; E_a, E_C, and I_C are all zero.

2-58. The reason that current can flow in the opposite direction at time T5 is based on electrostatic principles. When the applied voltage is decreased at time T5, the capacitor is charged to the maximum value of E_a. The DC source voltage becomes less than the voltage across the capacitor. The electrons charging plate A will move back toward the negative terminal of the DC source. Similarly electrons will move out of the positive terminal of the DC source toward plate B of the capacitor. Thus it can be stated that when applied voltage is decreased, current flow will reverse and the capacitor will discharge. This discharge will continue until the charge on the capacitor is again equal to E_a.

2-59. When a varying voltage is applied to a capacitor, the following statement applies. With a voltage increase (voltage rise), the capacitor charges and with a voltage decrease (voltage fall), the capacitor discharges.

2-60. Now we will apply an AC voltage to a capacitor. Figure 2-20A shows an AC voltage source connected to a capacitor. The graph in figure 2-20B shows the phase, time, and amplitude relationships between applied voltage (E_a), the voltage across the capacitor (E_C), and the current (I_C) charging and discharging the capacitor.

2-61. For this explanation, the minute time difference between E_a and E_C will not be expanded. Thus, the variations in E_a and E_C will be considered to occur at the same time. The graph in figure 2-20B assumes applied voltage to be at the start of its positive half-cycle (positive alternation).

2-62. At the instant voltage is applied (Time T1), maximum current flows because there is no charge on the capacitor. Between T1 and T2, applied voltage increases to maximum at a sinusoidal rate (a rate equal to the rate of change in sine values). E_a and E_C then, will be increasing at a constantly decreasing rate of change. I_C will decrease from maximum at time T1 to zero at time T2. Since the rate of increase for E_a is constantly decreasing the capacitor sees constantly less of a difference between E_a and E_C that it must charge to. This means less and less charging current is required and I_C will gradually decrease to zero.

2-63. At time T2, then, E_a and E_C are maximum and I_C is zero. E_a and E_C are at 90 degrees as they are at their maximum positive alternation value. I_C is at 180 degrees as it is at the end of its positive alternation. Thus I_C is leading E_a and E_C by 90 degrees.

2-64. Between time T2 and time T3, E_a decreases to zero. When E_a starts decreasing, the capacitor will start to discharge and current flows in the opposite direction. As explained earlier, when applied voltage decreases, the capacitor discharges. Since E_a is decreasing at a constantly increasing rate of change, E_C also decreases at a constantly increasing rate of change. As E_a and E_C decrease, I_C will be increasing. Why? Since E_a is decreasing at a steadily increasing rate of change, the capacitor sees a steadily increasing difference between E_a and E_C that it must discharge to. This causes the discharge current to increase. The discharge current is maximum as E_a reaches zero.

2-65. At time T3, then, E_a and E_C are at zero and I_C is at maximum value. E_a and E_C are at 180 degrees, which is the end of their positive alternation and the start of their negative alternation. I_C is at 270 degrees as it is at the maximum value of its negative alternation. I_C is leading E_a and E_C by 90 degrees.

2-66. Also at time T3, the polarity of the AC voltage reverses and E_a begins its negative alternation. Between time T3 and time T4, E_a increases at a constantly decreasing rate of change. When E_a starts increasing at time T3, maximum current will flow. The direction of this current flow will be the same as that of the discharge current between times T2 and T3. This is due to E_a reversing its polarity as it begins its negative alternation at time T3. Between time T3 and time T4, I_C decreases to zero as E_a and E_C increase to maximum.

2-67. At time T4, then, E_a and E_C are at the maximum value of their negative alternations and I_C is at zero. I_C is still leading E_a and E_C by 90 degrees.

2-68. Also at time T4, E_a starts decreasing which causes the capacitor to start discharging and current flow to reverse. Between time T4 and time T5, E_a and E_C decrease to zero and I_C increases to maximum.

2-69. At time T5, E_a and E_C are zero and I_C is at the maximum value of its positive alternation. I_C is leading E_a and E_C by 90 degrees.

2-70. After time T5 the second cycle of AC voltage is applied to the capacitor. The charge and discharge action of the capacitor is the same as it was for the first cycle. Two cycles of the AC sine wave voltage are shown so that you can readily see that both current and voltage vary in a sine wave pattern.

2-71. Summary: When an AC sine wave voltage is applied to a pure capacitive circuit, the following statements apply.

a. A sine wave voltage will be developed across the capacitor that is equal to and in phase with E_a.

b. A sine wave of current will be developed in the circuit by the charge and discharge of the capacitor that leads E_a and E_C by 90 degrees.

c. When E_a and E_C are at the maximum value of their positive and negative alternations, current in the circuit is zero.

d. When E_a and E_C are zero (as they move from positive to negative alternations and negative to positive alternations), current in the circuit is maximum.

e. Even though no current flows through the capacitor, a continuous sine wave of current appears to flow through the circuit due to electrons entering and leaving the capacitor plates as the capacitor charges and discharges.

2-72. As noted previously, when a constant DC voltage is applied to a capacitor, the capacitor charges and current flow stops. A capacitor offers infinite opposition to current flow in a circuit with a constant DC voltage applied. But this is not the case when an AC voltage is applied to a capacitor. With an AC voltage applied, a continuous alternating current flows in the circuit as the capacitor charges and discharges. The amount of current flow is determined by the amount of opposition offered to current flow. What is this opposition, what determines it, and how is the amount of opposition determined?

2-73. Capacitive Reactance.

2-74. Capacitive reactance is defined as the opposition offered by a capacitor to the flow of an alternating current. The symbol for capacitive reactance is "X_C" and its unit of measurement is the ohm. The term CAPACITIVE REACTANCE is used with capacitors so the amount of opposition offered by a capacitor is not confused with the resistance of a resistor. Capacitive reactance is determined by the physical construction of the capacitor and by the applied frequency.

2-75. The first of the two factors that determine the capacitive reactance of a capacitor is its capacitance value. As you know, capacitance is the measure of the ability of a capacitor to store electrical energy. Capacitance is determined by the physical construction of the capacitor and is NOT affected by the type of voltage applied to the capacitor. The greater the capacitance of a capacitor, the more energy it can store. To store the energy, electrons must move into one plate of the capacitor and out of the other. Since capacitance is greater, more electrons are required to charge the capacitor. Thus as capacitance increases, the amount of charging current increases. As capacitive reactance is opposition to current flow, it must decrease as capacitance and the charging current increase. Capacitive reactance is inversely proportional to capacitance. Capacitive reactance decreases as capacitance increases.

2-76. The second factor that determines the capacitive reactance of a capacitor is the frequency of the AC voltage applied to it. Figure 2-21 is used to aid in explaining this fact. In figure 2-21A, a capacitor is connected in series with an AC voltage source. Two cycles of an AC voltage (as shown in figure 2-21B) is applied to the capacitor. Keep in mind that a capacitor stores energy when it charges and releases energy when it discharges. Remember that electron movement (current flow) is necessary for the charge and discharge of a capacitor.

2-77. In figure 2-21B, each cycle of the AC voltage represents a specific amount of time since $t = \frac{1}{f}$. In the previous discussion on AC capacitive circuits you learned that a capacitor charges both on the positive and negative alternation of the applied AC voltage. As the amount of energy stored in a capacitor is equal to its capacitance times the voltage applied ($Q = CE$), you can readily see that this amount of energy is stored two times in one cycle of the applied voltage.

2-78. Energy is stored during the time represented by the width of the shaded area in each alternation. The amount of energy stored is represented by the amplitude of the shaded area. Thus (in figure 2-21 B) during the time of two cycles, the capacitor has stored energy four times.

2-79. In figure 2-21C the frequency of the applied voltage is doubled. Since frequency has doubled, the time for one cycle of the AC voltage has decreased by half. This means then that the time to charge the capacitor has also decreased by one half. As capacitance and the AC amplitude remained the same, the amount of charge (Q) has not changed. Since there are now four cycles of the AC voltage in the same time period as the previous two cycles, the capacitor stores energy eight times in the same time period. This means that the current had to flow more often. Although the same amount of current flows to charge the capacitor each time in both figure 2-21B and 2-21C, it flows twice as many times in figure 2-21C. Therefore, the average value of current flow in the circuit increased. Since current flow increased, the opposition to current flow had to decrease. Thus as frequency increases, capacitive reactance decreases.

2-80. In figure 2-21D the frequency of the applied voltage is one half that of the voltage applied in figure 2-21B. Again capacitance and the amplitude of the applied voltage remain the same. With one half the frequency, both the time for one cycle and the time to charge the capacitor have doubled. With one cycle of the AC voltage in the same time period as the two cycles in figure 2-21B, the capacitor stores energy only two times in the same amount of time. Since current flowed only one half as many times to charge the capacitor, the average value of current flow decreased. As current flow decreased, the opposition to current flow had to increase. Thus as frequency decreases, capacitive reactance increases. Capacitive reactance is inversely proportional to frequency.

2-81. To develop the formula for capacitive reactance, an additional factor is taken into account. That factor is the time rate for the change of charge on the capacitor. This time rate represents the varying current that charges the capacitor as the applied voltage varies and it is equal to $1/2\pi$.

Thus the formula for capacitive reactance is:

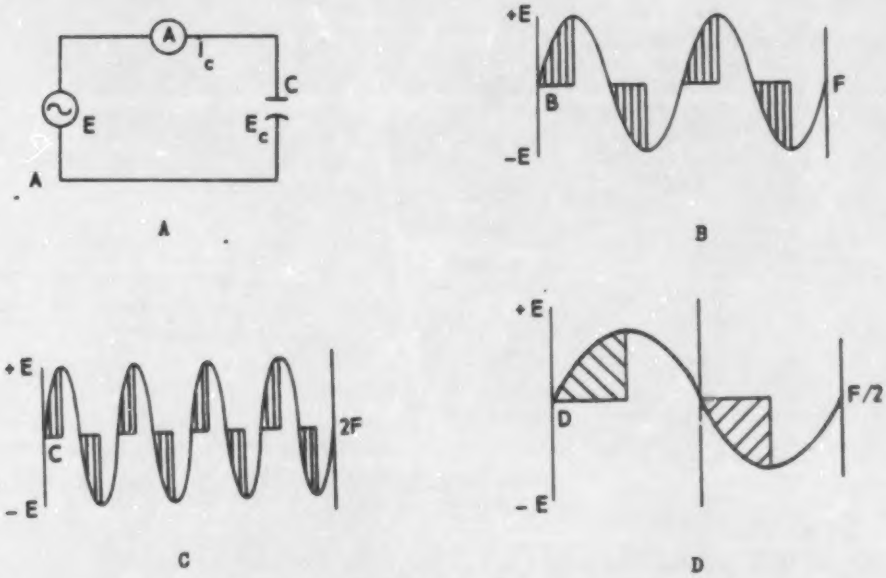


Figure 2-21. Capacitive Reactance

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$$X_C = \frac{1}{2\pi fC}$$

Where:

X_C = capacitive reactance in ohms

2π = 6.28

f = frequency in hertz

C = capacitance in farads

2-82. The basic formula for capacitive reactance may be further simplified by taking the reciprocal of 2π as follows:

$$X_C = \frac{1}{2\pi fC}$$

$$X_C = \frac{1}{6.28} \times \frac{1}{fC}$$

$$X_C = \frac{.159}{fC}$$

Also by transposing this formula you can solve for either frequency or capacitance, if the other two quantities are known. The transposed formulas are:

$$f = \frac{.159}{X_C C}$$

$$C = \frac{.159}{f X_C}$$

2-83. The next four examples will show the relationship between frequency, capacitance, and capacitive reactance as the exact amount of capacitive reactance is computed.

EXAMPLE 1:

Solve for capacitive reactance when the frequency is 6 kHz and the capacitor value is .05 μF.

$$X_C = \frac{.159}{fC}$$

$$= \frac{.159}{6 \text{ kHz} \times .05\ \mu F}$$

$$= \frac{.159}{(6 \times 10^3) \times (.05 \times 10^{-6})}$$

$$= \frac{.159}{.3 \times 10^{-3}}$$

$$= .53 \times 10^3$$

$$= 530 \text{ ohms.}$$

EXAMPLE 2:

Solve for capacitive reactance when the capacitor value is .05 μF and the frequency is 30 kHz.

$$X_C = \frac{.159}{fC}$$

$$= \frac{.159}{30 \text{ kHz} \times .05\ \mu F}$$

$$= \frac{.159}{(30 \times 10^3) \times (.05 \times 10^{-6})}$$

$$= \frac{.159}{1.5 \times 10^{-3}}$$

$$= .106 \times 10^3$$

$$= 106 \text{ ohms.}$$

From the first two examples you can see that as the frequency increased (with capacitance remaining the same), the capacitive reactance decreased.

EXAMPLE 3:

Solve for capacitive reactance when the frequency is 1 kHz and the capacitor value is .5 μF.

$$X_C = \frac{.159}{fC}$$

$$= \frac{.159}{1 \text{ kHz} \times .5\ \mu F}$$

$$= \frac{.159}{(1 \times 10^3) \times (.5 \times 10^{-6})}$$

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$$= \frac{.159}{.5 \text{ x } 10^{-3}}$$

$$= .318 \text{ x } 10^{3}$$

$$= 318 \text{ ohms}$$

EXAMPLE 4:

Solve for capacitive reactance when the frequency is 1 kHz and the capacitor value is .005 μF.

$$X_C = \frac{.159}{fC}$$

$$= \frac{.159}{1 \text{ kHz x } .005\ \mu\text{F}}$$

$$= \frac{.159}{(1 \text{ x } 10^{3}) \text{ x } (.005 \text{ x } 10^{-6})}$$

$$= \frac{.159}{.005 \text{ x } 10^{-3}}$$

$$= 31.8 \text{ x } 10^{3}$$

$$= 31.8 \text{ k ohms}$$

In examples 3 and 4 you can see that as the capacitance decreased (with frequency remaining the same), the capacitive reactance increased. In solving for capacitive reactance, you can see that X_C is inversely proportional to changes in frequency or capacitance.

2-84. A method for determining the total capacitive reactance (X_{Ct}) of series, parallel, and series-parallel AC capacitive circuits must be developed next. What you have learned about capacitors and capacitance will be applied.

2-85. Series Capacitors. Figure 2-22 shows two capacitors connected in series with a 1 kHz AC voltage source. Using the information given, two different methods will be used to find X_{Ct}. Also a formula for X_{Ct} in a series capacitive circuit will be developed.

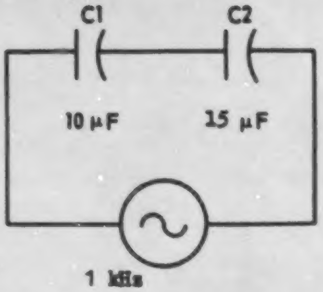

Figure 2-22 . Simple Series Circuit

2-86. The first method will find total capacitance and then, use total capacitance to find total capacitive reactance. As this is a series circuit:

$$C_t = \frac{C1 \text{ x } C2}{C1 + C2}$$

$$= \frac{(10 \text{ x } 10^{-6}) \text{ x } (15 \text{ x } 10^{-6})}{(10 \text{ x } 10^{-6}) + (15 \text{ x } 10^{-6})}$$

$$= \frac{150 \text{ x } 10^{-12}}{25 + 10^{-6}}$$

$$= 6 \text{ x } 10^{-6} \text{ farads}$$

$$= 6\ \mu\text{F}$$

Next total capacitance is used in the capacitive reactance formula.

$$X_{Ct} = \frac{.159}{fC_t}$$

$$= \frac{.159}{(1 \text{ x } 10^{3}) \text{x} (6 \text{ x } 10^{-6})}$$

$$= \frac{.159}{6 \text{ x } 10^{-3}}$$

$$= .0265 \text{ x } 10^{3}$$

$$= 26.5 \text{ ohms}$$

Using the second method, the value of capacitive reactance for each capacitor will be found and then added. Thus for C1:

$$X_{C1} = \frac{.159}{f(C1)} = \frac{.159}{(1 \times 10^{3}) \times (10 \times 10^{-6})}$$

$$= \frac{.159}{10 \times 10^{-3}}$$

$$= .0159 \times 10^{3}$$

$$= 15.9 \text{ ohms.}$$

For C2:

$$X_{C2} = \frac{.159}{f(C2)}$$

$$= \frac{.159}{(1 \times 10^{3}) \times (15 \times 10^{-6})}$$

$$= \frac{.159}{15 \times 10^{-3}}$$

$$= 10.6 \text{ ohms.}$$

Then for the total capacitive reactance add X_{C1} and X_{C2}.

$$X_{C_t} = X_{C1} + X_{C2}$$

$$= 15.9 + 10.6$$

$$= 26.5 \text{ ohms}$$

2-87. The value of total reactance using the second method is the same as that in the first method. Therefore, the rule for series capacitive circuits is: Total capacitive reactance in a series capacitive circuit is equal to the sum of the capacitive reactances in the circuit, and the formula is:

$$X_{C_t} = X_{C1} + X_{C2} + X_{C3} + \ldots$$

2-88. You learned earlier that when capacitors are connected in series, total capacitance decreases. Next you learned that capacitance and capactive reactance are inversely proportional. By combining these two facts, you can readily see that as capacitors are added in series, total capacitance decreases and total capacitive reactance increases. In addition, the rule for total capacitive reactance follows the basic rule for series circuits - total opposition in a series circuit is equal to the sum of the individual oppositions.

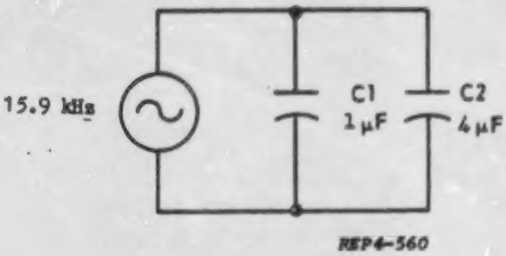

Figure 2-23. Simple Parallel Circuit

2-89. Parallel Capacitors. Figure 2-23 shows two capacitors connected in parallel with a 15.9 kHz AC voltage source. Two different methods will be used to find total capacitive reactance with the information given. As well, a formula for total capacitive reactance in a parallel capacitive circuit will be developed.

2-90. In the first method, total capacitance will be determined and then, total capacitance will be used to find total capacitive reactance.

$$C_t = C1 + C2$$

$$= 1 \mu F + 4 \mu F$$

$$= 5 \mu F$$

Next this value of total capacitance is entered into the capacitive reactance formula:

$$\text{As } X_{C_t} = \frac{.159}{fC_t}$$

$$= \frac{.159}{(15.9 \times 10^{3}) \times (5 \times 10^{-6})}$$

$$= \frac{.159}{79.5 \times 10^{-3}}$$

$$= .002 \times 10^{3}$$

$$= 2 \text{ ohms.}$$

In the second method, the value of capacitive reactance for each capacitor will be found first.

$$X_{C1} = \frac{.159}{f(C1)}$$

$$= \frac{.159}{(15.9 \times 10^3) \times (1 \times 10^{-6})}$$

$$= \frac{.159}{15.9 \times 10^{-3}}$$

$$= .01 \times 10^3$$

$$= 10 \text{ ohms.}$$

$$X_{C2} = \frac{.159}{f(C2)}$$

$$= \frac{.159}{(15.9 \times 10^3) \times (4 \times 10^{-6})}$$

$$= \frac{.159 \times 10^0}{63.6 \times 10^{-3}}$$

$$= .0025 \times 10^3$$

$$= 2.5 \text{ ohms.}$$

As this is a parallel circuit, a basic rule of parallel circuits is applied. This rule is: Total opposition in a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual oppositions in the circuit. Restating this rule: Total capacitive reactance in a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual capacitive reactances in the circuit. The formula:

$$X_{C_t} = \frac{1}{\frac{1}{X_{C1}} + \frac{1}{X_{C2}} + \frac{1}{X_{C3}} + \ldots} \qquad \text{For any number}$$

$$X_{C_t} = \frac{X_{C1} \times X_{C2}}{X_{C1} + X_{C2}} \qquad \text{For two}$$

$$X_{C_t} = \frac{X_C}{N} \qquad \text{For equal values.}$$

Thus the last part of the second approach is:

$$X_{C_t} = \frac{X_{C1} \times X_{C2}}{X_{C1} + X_{C2}}$$

$$= \frac{10 \times 2.5}{10 + 2.5}$$

$$= \frac{25}{12.5}$$

$$= 2 \text{ ohms.}$$

Therefore, either method gives the same value of total capacitive reactance. When capacitors are connected in parallel, total capacitance increases. Capacitance and capacitive reactance are inversely proportional. By combining these two facts, you can readily see that as capacitors are added in parallel, total capacitance increases and total capacitive reactance decreases.

2-91. Figure 2-24 shows four capacitors connected in series-parallel with an AC voltage source. Here the values of capacitive reactance are given for each capacitor. In this example, we need only apply the series and parallel total capacitive reactance formulas.

2-92. First, the effective capacitive reactance of the parallel network will be determined.

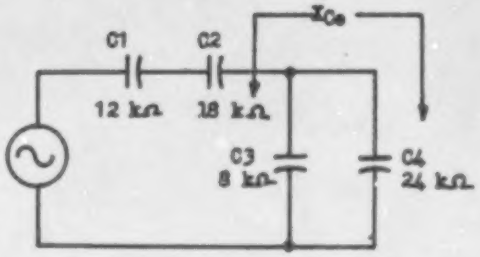

Figure 2-24. Simple Series-Parallel Circuit

$$X_{C_e} = \frac{X_{C3} \times X_{C4}}{X_{C3} + X_{C4}}$$

$$= \frac{(8 \times 10^3) \times (24 \times 10^3)}{(8 \times 10^5) + (24 \times 10^3)}$$

$$= \frac{192 \times 10^6}{32 \times 10^3}$$

$$= 6 \times 10^3 \text{ ohms}$$

$$= 6 \text{ k ohms}$$

As X_{C_e} is in series with the reactances of C1 and C2, we may solve for total capacitive reactance with the series formula.

$$X_{C_t} = X_{C1} + X_{C2} + X_{C_e}$$

$$= 12\ \text{k}\Omega + 18\ \text{k}\Omega + 6\ \text{k}\Omega$$

$$= 36\ \text{k}\Omega$$

2-93. As you have seen throughout this lesson the rules for voltage, opposition, and current in series, parallel, and series-parallel circuits apply to capacitive circuits just as they apply to resistive circuits. Therefore, the following formulas (stated in capacitive terms) for series and parallel capacitive circuits may also be used in addition to those covered in the preceding material.

Series: $E_a = E_{C1} + E_{C2} + E_{C3} + \ldots$

$I_t = I_{C1} = I_{C2} = I_{C3} = \ldots\ldots$

Parallel: $E_a = E_{C1} = E_{C2} = E_{C3} = \ldots\ldots$

$I_t = I_{C1} + I_{C2} + I_{C3} + \ldots\ldots$

2-94. Since the capacitive reactance is another type opposition to current flow, Ohm's law formulas also apply. Stated in capacitive terms, they are:

$$E_C = I_C X_C$$

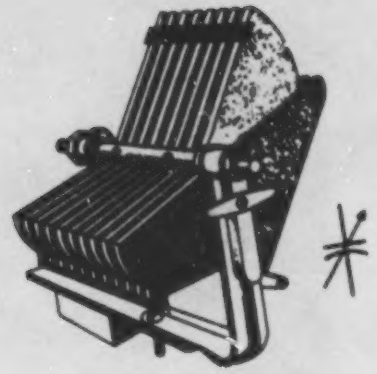

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Figure 2-25. Rotor-Stator Capacitor

$$X_C = \frac{E_C}{I_C}$$

$$I_C = \frac{E_C}{X_C}$$

2-95. Classes and Types of Capacitors.

2-96. Capacitors are divided into two general classes, variable and fixed.

2-97. Variable Capacitors. The capacitance value of capacitors in this class vary when a mechanical adjustment is made. The mechanical adjustment causes either plate area or dielectric thickness to change. This causes a change in the capacitance value. The following capacitors are two examples of variable capacitors.

a. The first type of variable capacitor is the rotor-stator capacitor, figure 2-25. You are probably familiar with this type because many radios use a rotor-stator capacitor to tune in stations. As the rotor turns, it causes the plates to mesh, varying the effective plate area and consequently the amount of capacitance. The rotor-stator capacitor normally has air for its dielectric.

b. The second type of variable capacitor is the compression capacitor. This type is shown in figure 2-26. The compression capacitor consists of plates separated with a mica dielectric. The capacitance is varied

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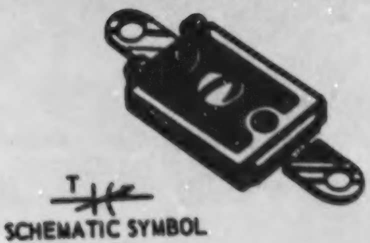

Figure 2-26. Compression Capacitor

by changing the distance between the plates, thus changing dielectric thickness. Tightening the screw causes the distance to decrease. Loosening the screw causes the distance to increase. An interesting point to note is that when the plates are completely compressed, the dielectric is only the mica. However, as the plates move further apart, the dielectric is a combination of mica and air.

2-26. Fixed Capacitors. Fixed capacitors have a fixed value of capacitance. They are generally named by the type of dielectric each uses.

The following capacitors are examples of fixed capacitors.

a. Electrolytic. The electrolytic capacitor's basic construction is shown in figure 2-27. The metal container is the negative terminal, the electrolyte is the negative plate, and a film of oxide on the positive plate acts as the dielectric. (Note: In this case, the capacitor type is NOT named for the type of dielectric used). The basic electrolytic capacitor has a definite polarity and is used only in DC circuits. If the polarity of the voltage were reversed, the oxide coating (dielectric) on the positive plate would break down and current would flow through the capacitor.

NOTE: Electrolytic capacitors can be constructed for AC operation by connecting two units back to back. The plates of such a capacitor have previously formed oxide films. The AC electrolytic capacitor is designed to present an insulating dielectric to both polarities. This capacitor is a special type of electrolytic capacitor and is

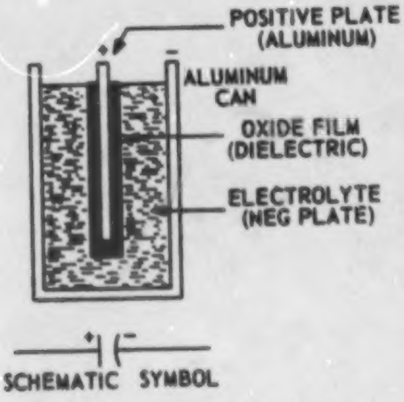

Figure 2-27. Electrolytic Capacitor

used only to satisfy special circuit requirements.

b. Paper Capacitors. Paper capacitors are in common use because of their low cost and small size. The dielectric material is usually waxed paper which is a porous material; therefore, paper capacitors are seldom used above 600 volts. The plates are long flat strips of tin foil and the paper is placed between them as the dielectric. All three are rolled together into a cylinder, as illustrated in figure 2-28. When rolled in this fashion, one plate has two active surfaces. The active area for calculation purposes, therefore, is twice the area of one plate. The completed cylinder is usually placed in a metal or cardboard container and sealed with wax, or pitch, to keep out the moisture. The outside foil is normally connected to the ground side of the circuit in order to create an electrostatic shield around the capacitor. The outside foil connection is normally indicated by a single color band at one end of the capacitor or by the work NEGATIVE at one end of the capacitor. On some capacitors, both the color band and the word NEGATIVE are used.

c. Oil Capacitors. Capacitors designed for large capacitance values used at high operating voltages are often oil-impregnated. The oil capacitor is similar in construction to the paper type. Although oil (by itself) has a lower dielectric strength than the waxed paper used in paper capacitors, paper impregnated with oil has a much higher dielectric strength. The oil capacitor operates at a lower temperature than ordinary paper capacitors. They are designed for use in high power circuits and are commonly used in transmitter circuits.

d. Mica. Mica capacitors have capacitance values between 5 and 50,000 picofarads (pF) and are used in circuits subjected to voltages up to 15,000 volts. These low capacitance components are used in high-frequency circuits. The high breakdown voltage of mica allows the high-frequency, high-voltage capacitors to be small in size compared to the same capacity and breakdown voltage of a paper capacitor. Physically alternate layers of tin foil (or aluminum foil) and mica are molded in a bakelite or plastic case. The finished product is durable and compact in design.

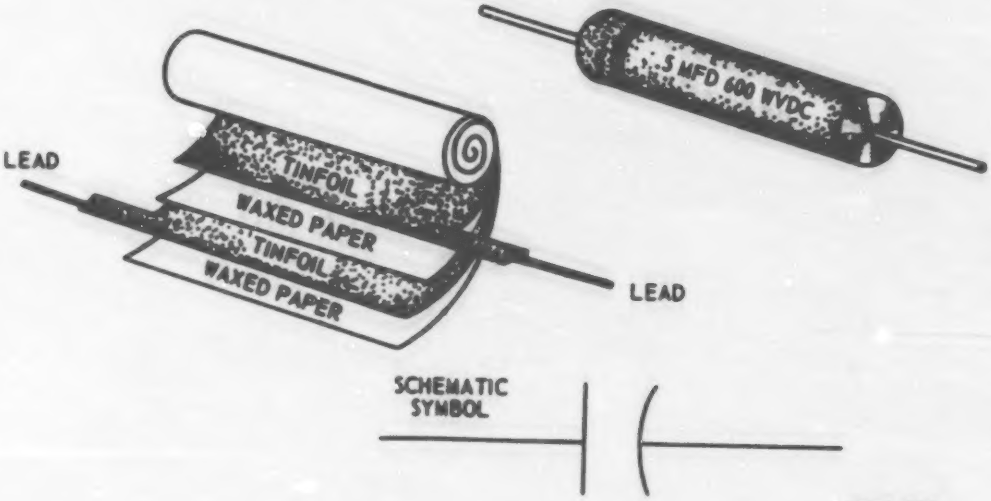

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Figure 2-28. Paper Capacitor

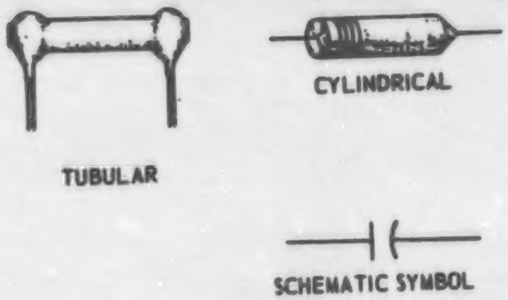

Figure 2-29. Ceramic Capacitors

e. Ceramic Capacitors. With the development of higher frequencies used in communications and television, there came a need for small capacitors with a high dielectric strength. The ceramic capacitor was designed to fill these needs. Ceramic capacitors range from 3.3 pF to 0.1 μF and can be used in low-power high-voltage circuits (up to 30,000 volts). They are extensively used in television high-voltage power supplies. The construction is quite simple: A hollow ceramic cylinder is coated inside and out with silver paint. Contacts to the coatings are placed at each end of the cylinder. The silver conductors are separated from each other by the ceramic cylinder. The ceramic capacitor is quite small physically, and because of their size, shape, and coloring, they are sometimes mistaken for resistors. Some typical shapes are shown in figure 2-29.

2-99. Capacitor Color Code.

2-100. The capacitance value and voltage rating may be stamped on the body of the capacitor, but sometimes values are indicated by color codes. Because there are so many shapes and sizes of capacitors, no one standard system has been adopted. Your ELECTRONIC HANDBOOK gives you a breakdown of some of the more commonly used systems. Usually, when you find it necessary to replace a capacitor in a piece of equipment, your best reference will be the equipment technical order.

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Chapter 3

INDUCTORS AND INDUCTIVE REACTANCE

3-1. In this chapter the effects of inductance in an electrical circuit will be explained. In order to understand this property of an inductor the following subjects will be discussed: Magnetism, Electromagnetism, Inductors and Inductive Reactance.

3-2. Magnetism.

3-3. Magnetism, like electricity, is another invisible force which has been known to man for many centuries. No one knows the full details as to what causes magnetism, but we can see how it works and what it does.

3-4. Magnetism is generally defined as that property of material that enables it to attract ferrous material. Magnetic materials, such as: Iron, steel, nickel and cobalt, that contain such properties are used for magnets.

3-5. There are natural magnets and artificial magnets. Natural magnets are found in nature and possess the property of attraction. For practical applications natural magnets are of little use except for the earth itself whose magnetic field directs magnetic compasses, which are widely used. It is possible to produce more powerful artificial magnets.

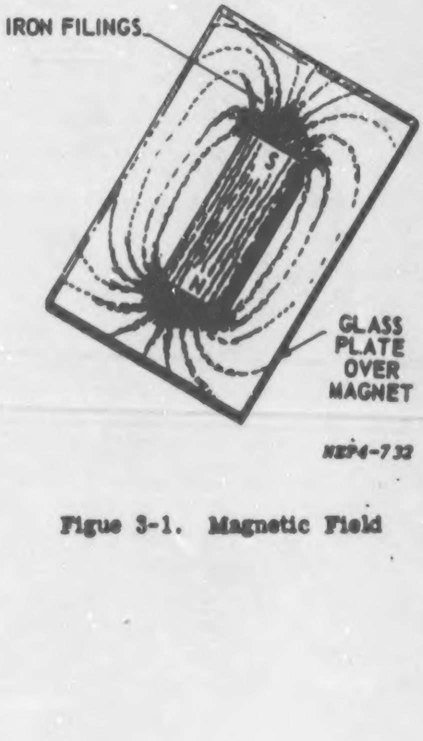
3-6. Magnets produced from magnetic materials are called ARTIFICIAL MAGNETS. They are usually classified as PERMANENT or TEMPORARY, depending on their ability to retain their magnetic properties after the magnetizing force has been removed.

3-7. The ability to retain magnetism is called the RETENTIVITY of the material. This depends on: (1) how much opposition a material offers to magnetic lines of force (RELUCTANCE), and (2) the ease with which magnetic lines of force distribute themselves throughout the material (PERMEABILITY). A permanent magnet would be produced from material having high retentivity. A temporary magnet would be produced from material having low retentivity. RESIDUAL MAGNETISM is the magnetism left after the magnetizing force has been removed. A material which has a high retentivity will have more residual magnetism.

3-8. MAGNETIC FIELD.

3-9. A concept called LINES OF FLUX or LINES OF FORCE is used to explain the things a magnet does. These are imaginary lines; you cannot see them. They represent magnetic force. The lines of flux around a magnet make up a pattern called a magnetic field. The effects of this force pattern can be shown by placing a sheet of glass on a magnet lying on a flat surface. Filings sprinkled on the glass will settle in a pattern of lines called flux lines or lines of force. This pattern is shown in figure 3-1.

3-10. LINES OF FORCE. To further describe and work with magnetic fields, lines represent the force existing in the area surrounding a magnet (refer to figure 3-2.) These lines, called MAGNETIC LINES OF FORCE, are invisible; but the iron filings (figure 3-1) illustrate their pattern in the magnetic field. The magnetic lines of force are assumed to emanate from the north pole of a magnet, pass through the surrounding space, and enter the south pole. Within the magnet they pass from the south pole to the north pole, thus completing a closed loop.



Figue 3-1. Magnetic Field

3-11. When two magnetic poles are brought close together, the mutual attraction or repulsion of the poles produces a more complicated pattern than that of a single magnet. These magnetic lines of force can be plotted by placing a compass at various points throughout the magnetic field, or they can be roughly illustrated by the use of iron filings as before. A diagram of magnetic poles placed close together is shown in figure 3-3.

3-12. Although magnetic lines of force are invisible, a simplified explanation of many magnetic phenomena can be explained by assuming the magnetic lines have certain real properties. The lines of force can be compared with rubber bands which stretch outward when a force is exerted upon them and contract when the force is removed. The characteristics of magnetic lines of force can be described as follows: They

a. are continuous and always form closed loops.

b. never cross one another.

c. tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.

d. pass through all materials, both magnetic and nonmagnetic.

e. always enter or leave a magnetic material at right angles to the surface.

3-13. MAGNETIC POLES. The magnetic force surrounding a magnet is not uniform. There exists a great concentration of force at the ends of a magnet and a very weak force at the center. Proof of this can be obtained by using iron filings (figure 3-1). It is found that many filings will cling to the ends of the magnet while very few adhere to the center. The two ends, which are the regions of concentrated lines of force, are called the POLES of the magnet. Magnets have two magnetic poles and both poles have equal magnetic strength.

3-14. If a bar magnet is suspended freely on a string, as shown in figure 3-4, it will align itself in a north and south direction. When this experiment is repeated, the same pole of the magnet will always swing toward the north pole of the earth. Therefore, it is called the north-seeking pole or simply the north pole. The other pole of the magnet is the south-seeking pole or the south pole.

3-15. A practical use of the directional characteristic of the magnet is the compass, a device in which a freely rotating magnetized needle indicator points toward the north pole. The realization that the poles of a suspended magnet always move to a definite position gives an indication that the opposite poles of a magnet have opposite magnetic polarity. The north pole of a magnet will always be attracted to the south pole of another magnet and will always be repelled by the north pole. The law for magnetic poles is: LIKE POLES REPEL, UNLIKE POLES ATTRACT. Figure 3-3 shows the patterns of the lines of force when the poles are placed near each other.

3-16. Theories of Magnetism.

3-17. There are two popular theories of magnetism, WEBER's THEORY and the DOMAIN THEORY. WEBER's THEORY considers the molecular magnets disarranged as in figure 3-5. This causes each molecular magnet to neutralize each other making the material unmagnetized. If all the molecular magnets were made to align themselves so that each added to each other as in figure 3-5, the material becomes magnetized. MAGNETIC INDUCTION is a method of magnetizing a bar of iron by stroking it with a magnet as shown in figure 3-5. Support for the WEBER THEORY is indicated when a bar magnet is divided in half, each is magnetized in the same direction as the original magnet. If this process is repeated many times each individual magnet will have a north and south pole in the same direction as the original bar magnet, figure 3-6.

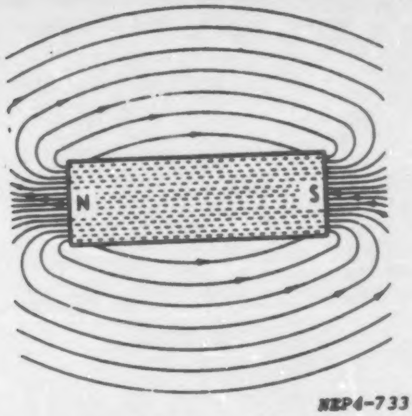


Figure 3-2. Lines of Force

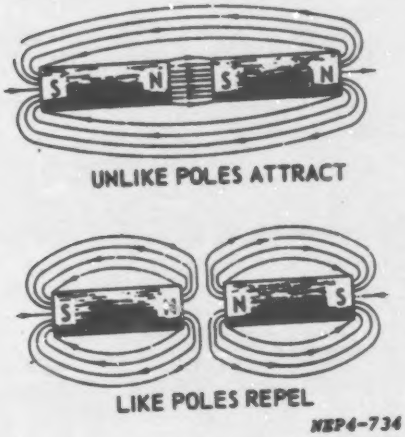


Figure 3-3. Attraction and Repulsion

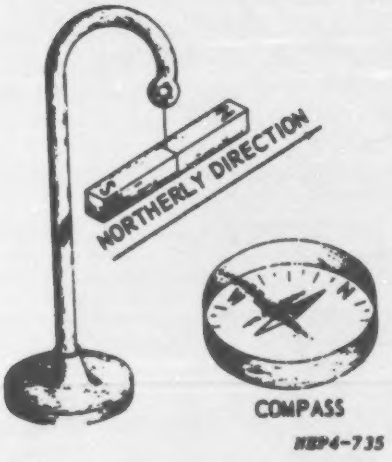


Figure 3-4. Compass Action

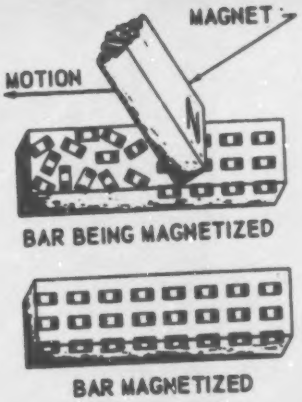


Figure 3-5. Magnetizing by Induction

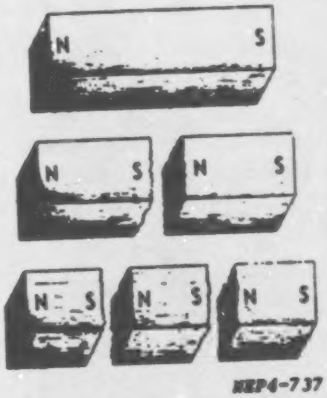


Figure 3-6. Weber Theory

3-18. The DOMAIN THEORY is based on the electron spin principle. It assumes that the electron not only developes an electric field but also a magnetic field, as it spins in its orbit. If an atom has equal numbers of electrons spining in opposite directions, the magnetic fields surrounding the electrons cancel one another, and the atom is demagnetized. If more electrons spin in one direction than another, however, the atom is magnetized.

3-19. When a number of magnetized atoms are grouped together, there is an interaction between their magnetic forces. The small magnetic force of the field surrounding the atom affects adjacent atoms, thus producing a small group of atoms with parallel magnetic fields. This group of magnetic atoms is known as a DOMAIN.

Throughout a domain there is an intense magnetic field without the influence of any external magnetic field. Since about 10 million tiny domains can be contained in one cubic millimeter, it is apparent that magnetic material is made up of a large number of domains. The domains in any substance are always magnetized to saturation, but usually randomly orientated throughout a material. Thus, the strong magnetic field of each domain is neutralized by opposing magnetic forces of other domains. When an external field is applied to a magnetic substance, the domains will line up with the external field. Since the domains themselves are naturally magnetized to saturation, the magnetic strength of a magnetized material is determined by the number of domains aligned by the magnetizing force. This theory of magnetism is known as the DOMAIN THEORY.

3-20. Electromagnetism.

3-21. Electromagnetism plays an important role in electronics. Before exploring the idea of electromagnetism, let's first define the term electromagnet: An electromagnet is an electrically excited magnet capable of exerting mechanical force. Present day examples of electromagnets include the starter solenoid on an automobile, electromechanical input-output devices used with computers, and the simple door bell. There are many more. Each of these particular devices operate on the principle of a current carrying conductor wrapped around a soft iron core.

3-22. By experimenting we can prove the existence of a magnetic field surrounding a conductor carrying DC. Figure 3-7 illustrates the procedure used. Note that a straight piece of wire is passed through a hole in a piece of glass and connected to a source of DC through a rheostat and switch. By sprinkling iron filings over the glass and then tapping it gently, the filings will arrange themselves in circles about the wire. If two magnetic compasses are placed on the glass, the compass needles will point in the direction of the magnetic lines of force. In this experiment the magnetic lines of force are traveling in a counterclockwise direction. The result of this experiment shows that a magnetic field does exist about a current carrying conductor and that the field also has direction.

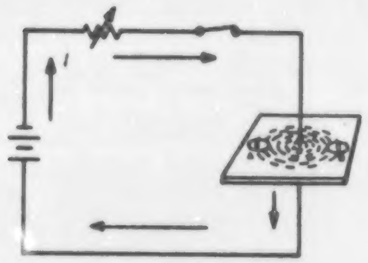


Figure 3-7. Electromagnetic Field (Counterclockwise)

3-23. If the battery is reversed, as shown in figure 3-8, the direction of the current in the circuit is reversed, the direction of both compass needles will change by 180°, indicating that the direction of the magnetic field is now clockwise about the wire.

3-24. Thus, a change in the direction of current produces a change in the direction of the magnetic field. The important point to remember with respect to the above experiment is that whenever an electric current is flowing, a magnetic field exists.

3-25. When the wire carrying the electric current is straight, the magnetic field about each point on the axis of the wire is circular. Figure 3-9 shows this circular field about several such points in the wire.

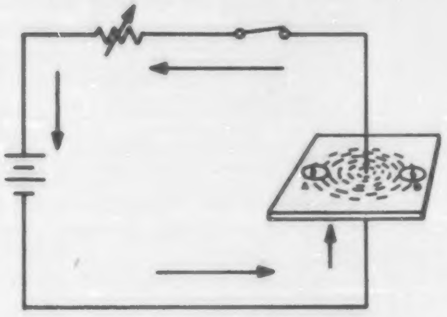


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Figure 3-8. Electromagnetic Field (Clockwise)

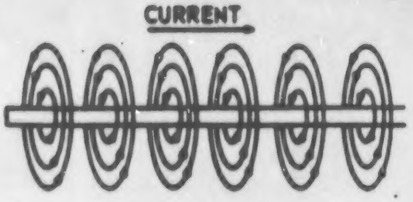


Figure 3-9. Magnetic Field Around a Wire

3-26. The easiest way to find the direction of the magnetic field about a straight wire carrying an electric current is by the LEFT-HAND THUMB RULE for conductors.

3-27. If you grasp the wire by your left hand so that your thumb points in the direction of the flow of electrons, your fingers curled about the wire will point in the direction of the magnetic field. Figure 3-10 shows the left-hand thumb rule for finding the relation between the direction of the magnetic field and the current in the conducting wire.

3-28. Figure 3-11A shows a cross-section of the wire and the magnetic field, and represents the way the field would appear if you looked at the end of the wire with current flowing away from you. The cross in the center of the wire is used to indicate that current is flowing away from you into the paper. You can find the direction of the magnetic field in such a diagram by placing your left thumb perpendicular to the paper and pointing toward it. The fingers of your left hand will then be in the direction of the field.

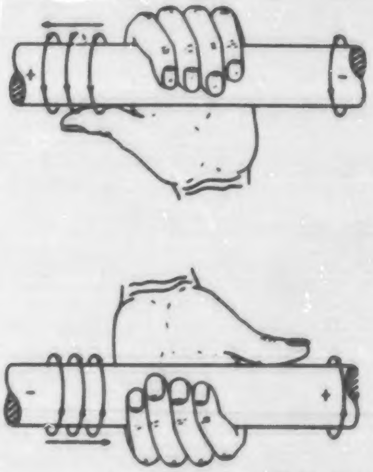


Figure 3-10. Left Hand Rule

3-29. Figure 3-11B shows a cross-section of the magnetic field about a wire in which the current is flowing out of the paper. Notice that the direction of the fields is the reverse of that of figure 3-11A. If you grasp the wire by your left hand so that your thumb is pointing directly upward from the paper, your fingers will point in the direction of the field. The dot in the center of the wire is used to indicate the current is flowing out of the paper toward you.

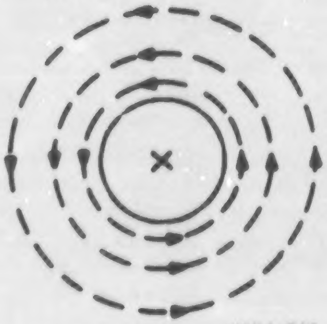


Figure 3-11A. Wire and Magnetic Field (Current into Paper)

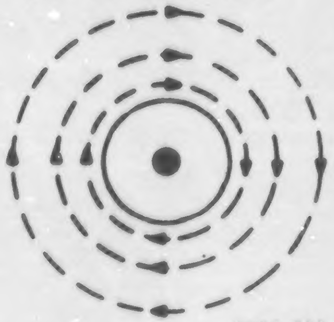


Figure 3-11B. Wire and Magnetic Field (Current out of Paper)

Figure 3-11.

3-30. Taking the straight wire shown in figure 3-9 and forming it into a loop as in figure 3-12, the left-hand thumb rule will show that the magnetic lines around the wire enter one face of the loop and all come out of other face. With current flowing in it, the loop of wire acts like a short bar magnet. The face of the loop that the lines enter is the south pole and the face that they leave is the north pole.

3-31. If you wind several loops to form a coil as shown in figure 3-13, a more powerful magnetic field will be created. Inside the coil, the lines are concentrated to form a very powerful field while outside the coil, they are spread out.

3-32. A coil like that of figure 3-13 with current flowing in it is an electromagnet and it is equivalent to a bar magnet. Its magnetic field has the same shape as the field of a bar magnet and it obeys the same laws of magnetism that a bar magnet obeys. That is, the unlike poles of two coils attract each other and the like poles repel. If the coil is free to rotate in a horizontal plane and is placed in a magnetic field, it will rotate, as will a compass needle, to take position such that the lines inside the coil are parallel to the lines of the field. The easiest way to find the north pole of a current carrying coil is by using the LEFT-HAND THUMB RULE.

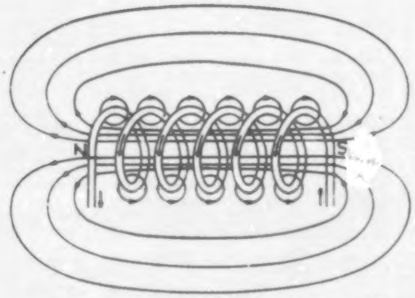


Figure 3-13. Magnetic Field of a Coil

3-33. If you grasp the coil by your left hand so as to allow your fingers to point in the direction of current flow, your thumb will point toward the north pole. In figure 3-13, the magnetic lines of force are leaving the north pole of the coil and entering at the south pole.

3-34. The strength of electromagnets may be increased by increasing the magnetizing force. MAGNETIZING FORCE for an electromagnet is the amount of current through the coil times the number of turns of the coil. More current will set up more lines of force and thus, make a more powerful magnetic field. Also, the more turns of wire wrapped around the core, the stronger the field. A field of a given strength can be produced by using many turns of wire carrying a small current or by using few turns

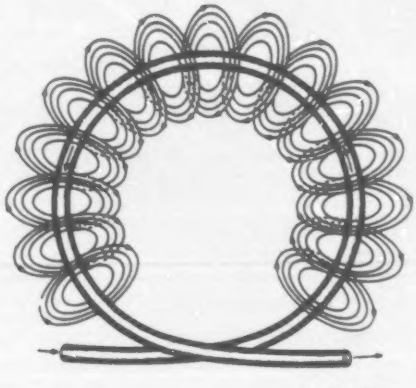


Figure 3-12. Magnetic Field of a Loop

of wire carrying larger current. Thus, an electric-current of 2 amperes flowing in a coil of 5,000 turns will produce the same number of lines as a current of 20 amperes flowing in a coil of 500 turns. The product of the number of turns in a coil and the amperes flowing in the coil is called the ampere-turns of the coil. Two coils with the same number of ampere-turns will, if their cores are identical, produce magnetic fields of the same strength. The same product of amperes and turns gives the same effect, no matter what the separate values of current and turns may be.

3-35. If you place a bar of iron or soft steel in the magnetic field of a coil (see figure 3-14), the bar will become magnetized. The bar has so much less reluctance than air, that thousands of additional magnetic lines are produced by the same current. The characteristic of magnetic lines to shorten themselves causes the bar to be pulled into the coil until the bar is centered in the coil, where the field is most intense. The bar becomes magnetized by the field of the coil in such a way as to be attracted into the coil.

3-36. If, in a given coil containing an iron core, the current is continually increased, a point is reached where further increases in current do not produce corresponding increases in the number of lines of flux. When this point is reached, the core is said to be SATURATED. Sometimes, the current in the coil is deliberately made so large that saturation of the core takes place. The magnetic field, in any electromagnet, is concentrated in the interior of the coil. The number of magnetic lines will be dependent on the permeability (μ) of the core material. The number of magnetic lines per unit of area is called flux density. By increasing the magnetizing force (H), flux density (B) will also increase. This can be expressed as $B = \mu H$.

3-37. Inductance and Inducting Voltage.

3-38. Inductance. The property of a circuit which opposes any change in current flow is called INDUCTANCE. All circuits have inductance. The opposition, however, takes place only when there is a change in current flow. INDUCTANCE does NOT oppose current flow, only a CHANGE in current flow. Where current is constantly changing, as in an AC circuit, opposition caused by inductance is always present. The symbol for inductance is the capital letter "L".

3-39. Inductance opposes a change in current flow. This opposition is due to counter EMF (CEMF). Counter EMF is an opposing induced voltage caused by self inductance. The requirements for an induced voltage are: a magnetic field, a conductor, and relative motion.

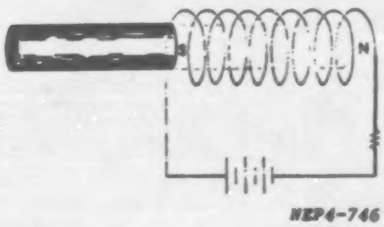


Figure 3-14. Magnetic Core

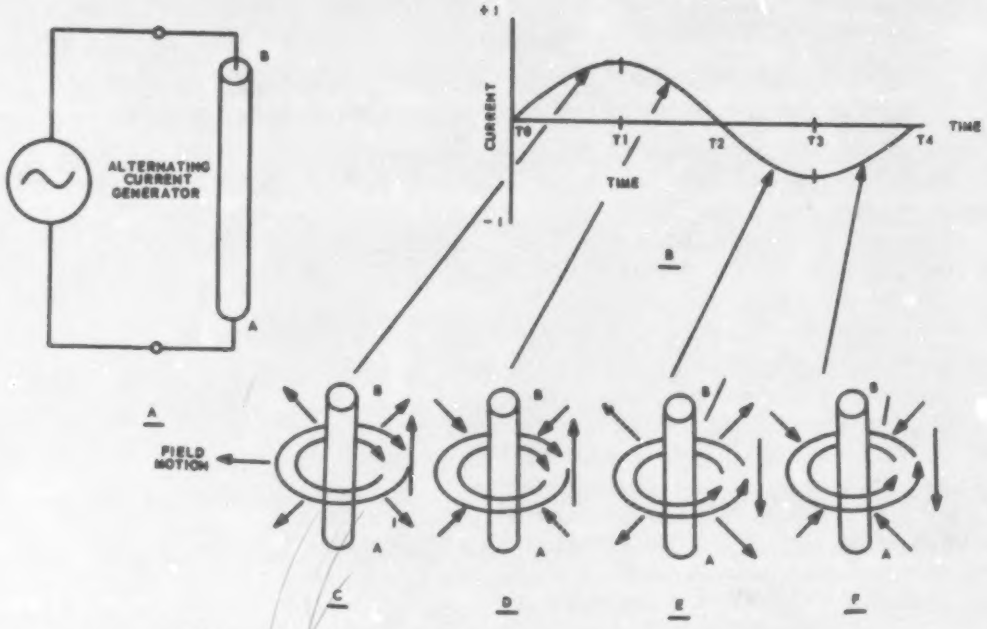


Figure 3-15. Magnetic Fields for Alternating Current

3-40. In figure 3-15A we have a conductor with an alternating current applied from the generator. At time T0, in figure 3-15B, the current waveform is at zero, representing no current flow in the conductor, and there is no magnetic field. From T0 to T1 the current is increasing and is flowing from A to B in the conductor shown in figure 3-15A. This increase in current flow produces an expanding (or moving) magnetic field around the conductor. This magnetic field (shown in figure 3-15C) cuts the conductor as the field expands. We now have a conductor, a magnetic field, and the relative motion necessary for induction.

3-41. When the current decreases from maximum to zero (during the interval T1 to T2, figure 3-15B), the magnetic field collapses and cuts the conductor in the opposite direction. We again have a conductor, a magnetic field, and relative motion. The same sequence of events occurs during the interval T2 and T4, except that the current in the conductor (figure 3-15A)flows from B to A and produces an opposite polarity of magnetic field. In all cases, the induced voltage opposes the change in current amplitude or direction.

3-42. To increase the property of inductance, the conductor is formed into a loop or coil. In figure 3-16, we have a conductor which forms 2-1/2 loops or turns. Current flow through one loop produces a magnetic field that encircles the loop in the direction shown (figure 3-16A). As current increases, the magnetic field expands and cuts all loops (figure 3-16B). The current in every loop affects all other loops. The field cutting other loops has the effect of increasing the opposition to a current change. There are four physical factors which affect the inductance of a single-layer coil. They include: (a) the number of turns in the coil, (b) the diameter of the coil, (c) the coil length, and (d) the type of material used for the core.

3-43. First, let us see how the number of turns affects the inductance of a coil. Figure 3-17 shows two coils. Coil A has two turns, and coil B has four turns. On coil A, the field set up by one loop cuts one other loop. On coil B, the field set up by one loop cuts three other loops. Doubling the number of turns in the coil will produce a field twice as strong using the same current. A field twice as strong cutting twice the number of

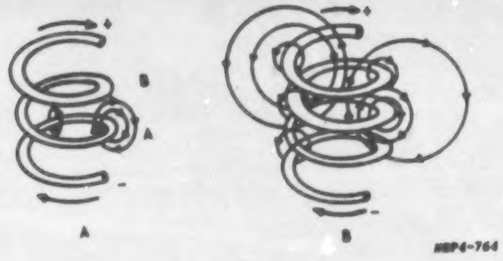


Figure 3-16. Inductance

turns will induce four times the voltage. The inductance then varies as the square of the number of turns.

3-44. The second factor is the coil diameter. In figure 3-18 you can see that coil B has twice the diameter of coil A. Recall that magnetic lines repel each other; the greater cross-sectional area of coil B, therefore, provides an easier path for the magnetic flux than the cross-sectional area of coil A. Again, this has the effect of increasing the strength of the magnetic field and, in turn, increasing the inductance of the coil. The inductance of a coil increases directly as the cross-sectional area of the core increases. Recall the formula for the area of a circle: $A = \pi r^2$. Doubling the radius of a coil, therefore, increases the inductance by a factor of four.

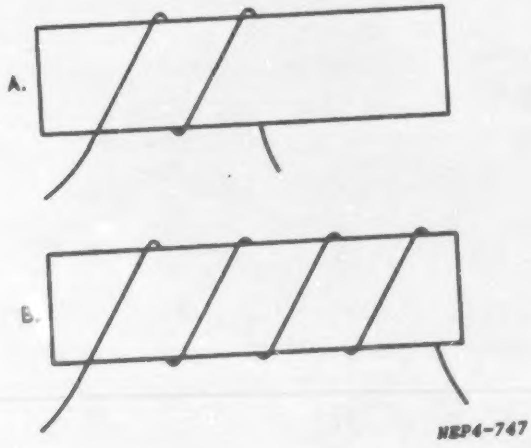


Figure 3-17. Inductance Factor (Turns)

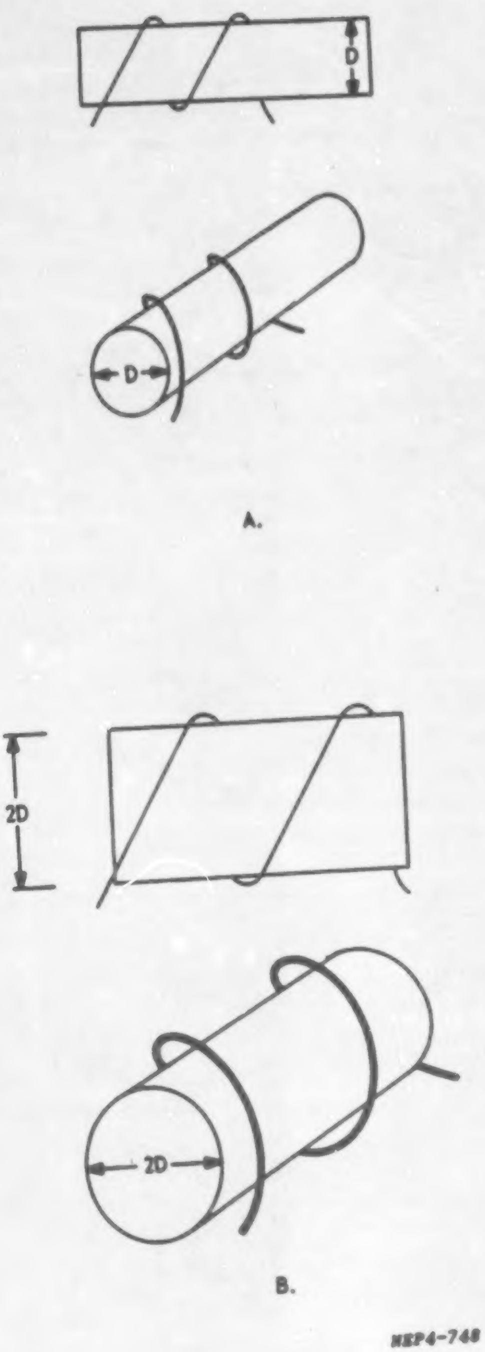
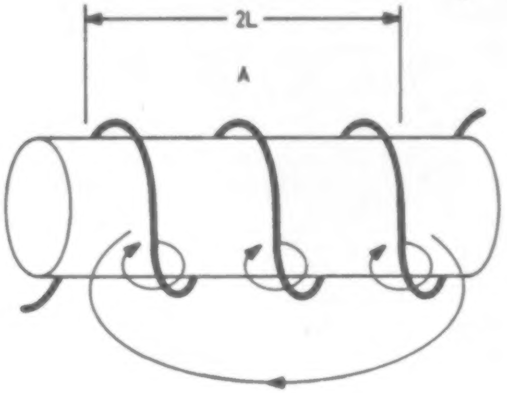


Figure 3-18. Inductance Factor (Diameter)

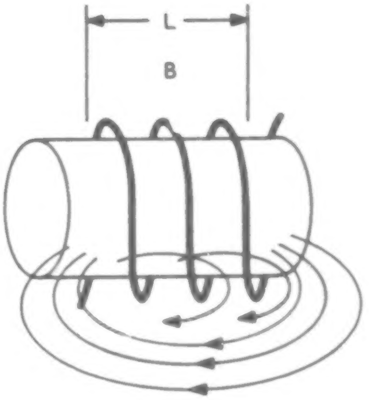
3-45. The third factor that affects the inductance of a coil is the length of the coil. Figure 3-19 shows the examples of coil spacings. Coil A has three turns, rather widely spaced making a relatively long coil. A coil of this type has few flux linkages, due to the space between each turn, and therefore, low inductance. Coil B has closely spaced, turns making a relatively short coil. This close spacing increases the flux linkage, increasing the inductance of the coil. Doubling the length of a coil halves its inductance.

3-46. The fourth physical factor is the type of core material used with the coil. Figure 3-20 shows two coils: coil A with an air core, and coil B with a soft iron core. The magnetic core of coil B is a better path for magnetic lines of force than the nonmagnetic core of coil A. The magnetic core's high permeability has less reluctance to the magnetic flux, resulting in more magnetic lines of force. This increase in the magnetic field increases the number of lines of force cutting each loop of the coil, thus increasing the inductance of the coil.

3-47. The unit of inductance (L) of a coil is the henry (H). A coil which developes a CEMF of one volt when the current is changing at the rate of one ampere per second has an inductance of one henry. For the single-layer coil, we can develop an expression which shows the relationship of the four physical factors which approximates the inductance:



WIDELY SPACED



CLOSELY WOUND

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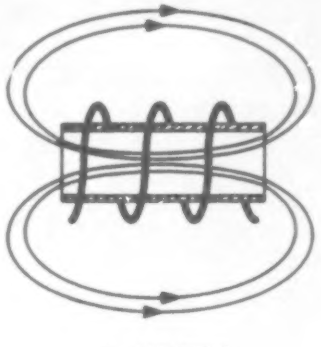
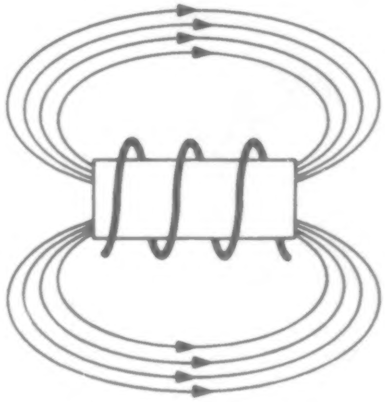
Figure 3-19. Inductance Factor (Coil Length)



A. AIR CORE



B. SOFT IRON CORE

Figure 3-20. Inductance Factor (Core Material)

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$$L = \frac{N^2 A\mu}{\ell} \times k$$

Where:

L = Inductance

N = Number of turns

A = Cross-sectional area of the core

μ = Permeability of the core material

ℓ = Length of the coil

k = Constant

3-48. An additional factor to increase inductance is to layer-wind the coil. Figure 3-21 shows a coil using close spacing and wound in layers. This has the effect of obtaining maximum flux linkage. Thus, the layer-wound coil has larger inductance values than the same size single-layer coil.

3-49. Total Inductance.

3-50. Many times you will come across circuits with several inductors in them. These inductors may be connected either in series or in parallel. The rules for computing the total inductance in a series or parallel inductance circuit are similar to the series or parallel resistance circuit.

3-51. Figure 3-22 illustrates three coils (A, B, and C) connected in series in an AC circuit. Coil A introduces a certain amount of inductance, coil B adds to this inductance, and finally coil C adds to the total of A and B. In order to find the total inductance in a series circuit, you must add the inductance of all the coils. The formula for total inductance of coils connected in series is:

$$L_t = L1 + L2 + L3 + \ldots\ldots\ldots + L_n$$

Let us substitute the following values of inductance in figure 3-22: A = 12 henries; B = 7 henries; and C = 3 henries.

$$L_t = L1 + L2 + L3$$

$$L_t = 12\text{ H} + 7\text{ H} + 3\text{ H}$$

$$L_t = 22\text{ H}$$

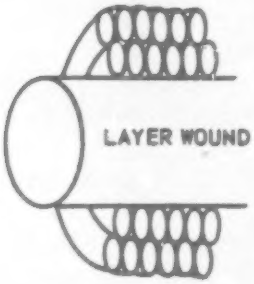

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Figure 3-21. Inductance Factor (Layer Winding)

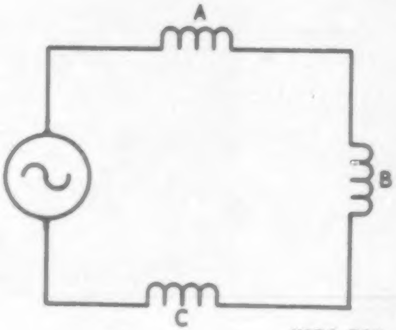

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Figure 3-22. Series Circuit

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3-52. Now let us see what happens when we have three coils in parallel as shown in figure 3-23. The coils X, Y, and Z provide three paths for current. The current that goes through coil X is opposed only by the inductance of coil X. The same is true of the current going through coil Y and coil Z. The formula for computing the total inductance of a parallel circuit, therefore, is as follows:

$$L_t = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3} + \ldots}$$

Now, let us substitute some values for X, Y, and Z of figure 3-23 as follows:

X = 8 henries

Y = 16 henries

Z = 16 henries

$$L_t = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3} + \ldots}$$

$$L_t = \frac{1}{\frac{1}{8H} + \frac{1}{16H} + \frac{1}{16H}}$$

$$L_t = \frac{1}{\frac{4}{16H}}$$

$$L_t = 4\ H$$

3-53. The series and parallel methods of calculating equivalent inductance can be applied to any series-parallel circuit containing inductors. When solving for total inductance in a series-parallel circuit, compute the equivalent inductance for the parallel inductances and then for series inductors. After each equivalent has been calculated solve the resulting circuit by substituting the equivalent inductances in the circuit.

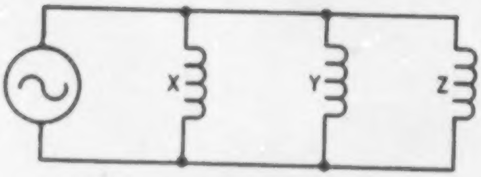


Figure 3-23. Parallel Circuit

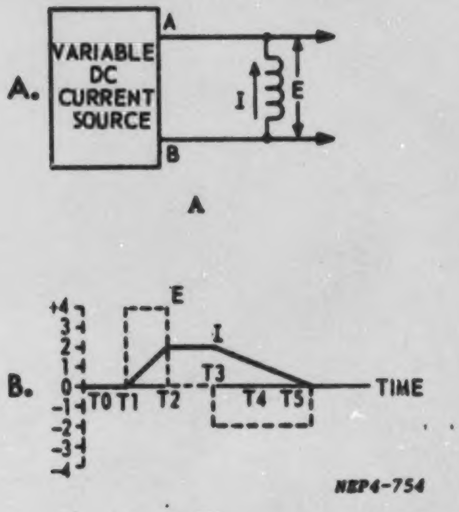
3-54. Notice that the formulas for computing total inductance of inductors connected in series and parallel resemble the formulas for resistors connected in series and parallel. An important thing to keep in mind, however, is that these formulas apply providing the flux linkages of one coil do not cut any other coil.

3-55. Inductive Reactance.

3-56. We have mentioned that an inductor opposes a change in current flow. Knowing this fact, you can see that an inductor has very little effect on direct current. A sine wave of alternating current, however, is continually changing. This means that the magnetic field in an AC circuit is continually changing, generating a CEMF which is continually opposing the change in current. In order to understand the effects of an inductor in a circuit, we'll analyze the effects of an inductor in a circuit with a variable current source.

3-57. In figure 3-24A, we have an inductor connected to a variable current source. The graph in figure 3-24B shows the relationship that exists between the current (I) through and the voltage (E) developed across an inductor with respect to time. The solid line represents the current and the dotted line represents the voltage. This magnetic field expands and collapses.

3-58. From T0 to T1, both current and voltage are zero. When current flow increases at a linear rate, as from T1 to T2, it produces a magnetic field which expands at a



A

B

Figure 3-24. DC Voltage-Current Relationship

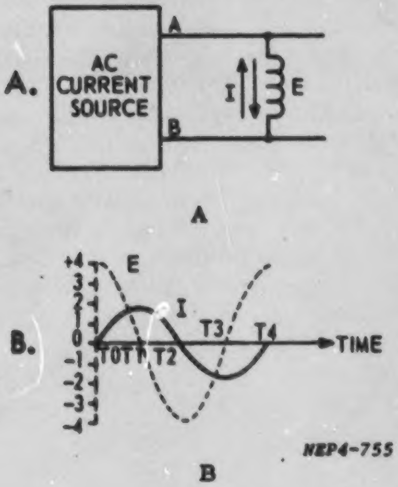
linear rate. This linear change in magnetic field induces a fixed voltage (E) across the inductor. With no change in current, as from T2 to T3, there is no change in magnetic field, and thus no voltage is induced. The induced voltage (E) equals zero whenever there is no relative motion between the magnetic field and conductors.

3-59. When current flow decreases at a linear rate, as from T3 to T5, the magnetic field collapses at a linear rate. This linear change in flux induces a constant voltage which is opposing the current decrease. Notice the polarity of the induced voltage caused by the collapsing field, from T3 to T5, is reversed from the polarity of voltage developed by the expanding field, from T1 to T2.

3-60. Also note that the rate of change of current determines the amount of induced voltage. From T1 to T2, the rate of change is twice as fast as from T3 to T5. Current increased from 0 to 2 in one unit of time (T1 to T2), but it decreased from 2 to 0 in two units of time (T3 to T5). Therefore, the voltage developed from T1 to T2 is twice the amplitude (+4 units) as from T3 to T5 (-2 units).

3-61. Now let's apply a sine wave of alternating current to the inductor to see what happens. Refer to figure 3-25. At time T0, if the sine wave of current has the same initial rate of change as shown at T1 in figure 3-24, the voltage induced will be equal to that developed at T1 (+4 units). As the rate of change of current gradually increases, from T0 to T1, the voltage induced decreases. At T1, the current stops increasing. At this time, we have a zero rate of change and the induced voltage will be zero. As the current flow decreases (T1 to T2), its magnetic field collapses and the polarity of the voltage induced across the inductor reverses. Notice that at T1, with zero rate of change, E = 0. As the rate of change of current decreases to minimum at T2, where even the direction of current flow changes, E = maximum with reversed polarity from T0 (-4 units).

3-62. Assume that current flow through the coil is from B to A, during time T0 to T2. The current through the coil forms an electromagnet which has one polarity. During the next half-cycle (T2 to T4), current flows from A to B and the electromagnet formed by the current has the opposite polarity. The electromagnet's polarity depends on current and has no relation to the voltage induced by the changing current.



A

B

Figure 3-25. AC Voltage-Current Relationship

3-63. In all cases, the AMPLITUDE of the induced voltage is determined by the rate of change of current flow. The POLARITY of the induced voltage is determined by two factors: the direction of current flow and whether it is increasing or decreasing. The induced voltage opposes any change in current flow. If current is increasing, induced voltage opposes the increase; if current is decreasing, induced voltage opposes the decrease. Of special interest is the fact that for the sine wave of current, there is a sine wave of voltage. Refer to figure 3-26. Maximum CEMF is produced at the first instant AC is applied to a coil. Anytime the current is going from zero (0) to some other value at the maximum rate of change, CEMF is maximum. During this time the inductor appears as an open. An open has maximum voltage across it. When the CEMF is overcome current begins to flow through the coil. Effectively, this happens in a purely inductive circuit and because of this, we say that current lags the applied voltage across an inductor by 90°.

3-64. The inductor reacts to the changing current by producing CEMF. This CEMF is produced by the expanding magnetic field which stores energy and the collapsing of the magnetic field which restores the energy back to the circuit. Because the energy is restored back to the circuit the inductor dissipates NO power. The opposition an inductor offers is called REACTANCE. The symbol for reactance is X. The reactance of a coil is INDUCTIVE REACTANCE. The symbol for inductive reactance is X_L and is defined as the opposition to alternating current flow offered by the inductance of a circuit. We can calculate the inductive reactance of a circuit by using the formula:

$$X_L = 2\pi fL$$
$$= 6.28\ fL$$

where X_L = inductive reactance in ohms

$2\pi = 6.28$

f = frequency in hertz

L = inductance in henries

3-65. As you can see by the formula, there are two variables which affect inductive reactance. They are inductance and frequency. You will find that since inductive reactance is opposition to alternating current flow, we use the same unit of measure as we do for resistance.

3-66. Now let us look at two examples to see how a change in frequency affects the inductive reactance. If a frequency of 60 hertz is applied to an inductance of 8 henries, as shown in figure 3-27, what is the inductive reactance?

Solution:

$$X_L = 6.28\ fL$$
$$X_L = (6.28) \times (60) \times (8)$$
$$X_L = 3014.4 \text{ ohms}$$

3-67. Now let's take the same coil and apply a frequency of 120 hertz as shown in figure 3-27B.

Solution:

$$X_L = 6.28\ fL$$
$$X_L = (6.28) \times (120) \times (8)$$
$$X_L = 6028.8 \text{ ohms}$$

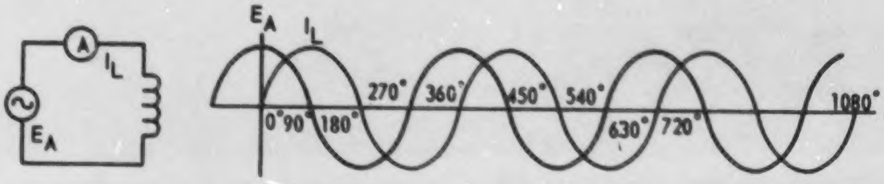


Figure 3-26. Phase Relationship

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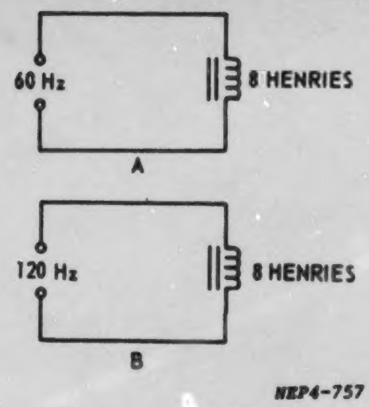

Figure 3-27. Inductive Reactance (Frequency)

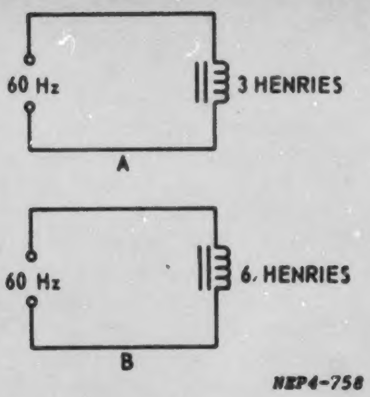

Figure 3-28. Inductive Reactance (Inductance)

Notice that when the frequency applied to the circuit increases, the inductive reactance increases. X_L is directly proportional to f.

3-68. Now let us look at two examples to see how a change in inductance affects the inductive reactance. Connect a coil with an inductance of 3 henries in a circuit with a frequency of 60 hertz, as shown in figure 3-28A, and compute the inductive reactance.

Solution:

$X_L = 6.28\,fL$

$X_L = (6.28) \times (60) \times (3)$

$X_L = 1130.4$ ohms

3-69. Now substitute a 6-henry coil for the 3-henry coil. The circuit now looks like the one shown in figure 3-28B.

Solution:

$X_L = 6.28\,fL$

$X_L = (6.28) \times (60) \times (6)$

$X_L = 2260.8$ ohms

Notice, in this case, that we increased the inductance of the coil which increased the inductive reactance of the circuit. X_L is directly proportional to L.

3-70. In inductive circuits which contain inductors in series, parallel, and series-parallel, we solve for total reactance in the same way as we solved for total resistance in resistive circuits.

3-71. Types of Inductors.

3-72. Figure 3-29 shows the symbols for several inductors: "A" has an air core, "B" has a fixed magnetic core, and "C" has a variable magnetic core. The air-core inductor is often used in radio-frequency (RF) circuits while the fixed magnetic core inductor finds numerous applications in audio-frequency (AF) and power circuits. The variable magnetic core inductor is used in both AF and RF circuits.

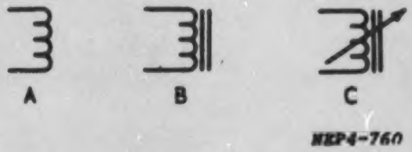

Figure 3-29. Inductor Symbols

3-73. In an earlier lesson, you learned that power frequencies of 60 and 400 hertz are within the range of audio frequencies. For this reason, power and audio-frequency inductors are similar in construction. The main differences between the two are the type of core material and the size of the wire in the coil. The power inductor is wound with larger wire to handle larger amounts of current than the audio-frequency inductor. Both have laminated cores, but core losses are held to a minimum in the audio inductor by using thinner laminations.

3-74. The RF inductor is used in circuits having frequencies above 20,000 hertz. The RF inductor normally has an air core, but may have a fixed or variable magnetic core.

3-75. Let's look at the physical characteristics of the three types of inductors dicussed:

POWER	- laminated iron core
	- medium to large size
	- large wire
AUDIO	- laminated iron core
	- small to medium size
	- small wire
	- special winding techniques
RF	- air - or powdered-iron core
	- small size
	- few turns
	- special winding styles

3-76. Inductor Losses.

3-77. Due to the physical and electrical characteristics of a coil, when current is applied there are power losses. Power loss is defined as energy dissipated without accomplishing work. There are three types of power loss in an inductor: copper loss, hysteresis loss, and eddy current loss. Methods have been devised to reduce each of these losses.

3-78. The first of the three types of inductor loss we will discuss is the copper loss. Copper loss results from the resistance of the conductor used to wind the coil. It is a heat loss which can be reduced by increasing the size of the conductor, or by using a material of lower resistance for the conductor. Normally, copper loss is reduced by increasing the conductor size. The only conductor material having less resistance than copper is silver.

3-79. The second inductor loss is hysteresis loss. As you know, the core of a coil is magnetized whenever a current is flowing in the coil. If AC is applied to the coil, the core is magnetized first in one direction, and then in the other direction. When a material is magnetized, the molecules of the material align themselves with the magnetic field. Every time the magnetic field reverses, the molecules realign themselves. This constant reversal of the molecules causes molecular friction, thereby producing heat. Hysteresis loss is reduced by using high permeability material for the core. The higher permeability material has less molecular friction.

3-80. The third inductor loss is eddy currents. Eddy currents are currents which are induced in the core of the inductor. You remember our requirements for inducing a voltage: a conductor, a magnetic field, and relative motion. In this case, the core is the conductor which is cut by the expanding and collapsing fields of the coil, inducing current in it. Eddy currents cause heat in the core.

3-81. Eddy currents are reduced by laminating the core. A laminated core is one made up of thin sheets of metal, electrically insulated from one another as shown in figure 3-30. The insulation does not oppose the magnetic flux, but it does reduce the eddy currents by limiting the paths for current flow.

3-82. Often you will see inductors referred to as CHOKES or CHOKE COILS. These terms are very descriptive of the characteristics of an inductor. In other words, an inductor tends to choke or oppose any change in current in a circuit.

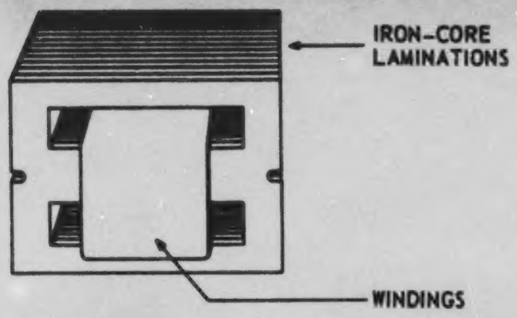

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Figure 3-30. Core Construction

3-83. To better understand the two reactive components, capacitors and inductors, it is well to compare some of their electrical characteristics (see figure 3-31).

CAPACITANCE	INDUCTANCE
The property that opposes a change in voltage.	The property that opposes a change in current.
Opposition (X_C) varies inversely with frequency.	Opposition (X_L) varies proportionally with frequency.
Opposition (X_C) varies inversely with C.	Opposition (X_L) varies proportionally with L.
Capacitors in parallel, C_t becomes larger.	Inductors in parallel, L_t becomes smaller.
Capacitors in series, C_t becomes smaller.	Inductors in series, L_t becomes larger.
Capacitor current leads E_C by 90 degrees.	Inductor current lags E_L by 90 degrees.
Large current flow to charge C opposes voltage changes.	Large CEMF induced to oppose changes.

Figure 3-31. Reactance Comparison

Chapter 4

TRANSFORMERS

4-1. Transformers are used in many different types of circuits. Their use depends on the circuit configuration. No matter how the transformer is used the basic principles of electromagnetic induction are employed.

4-2. Electromagnetic Induction.

4-3. In the previous chapter, inductance was discussed and explained. When current flowed through a coil of wire, a CEMF was produced as the magnetic field cut the turns of the coil. This process of producing a voltage, by an expanding or collapsing magnetic field, is called ELECTROMAGNETIC INDUCTION. There are three requirements for induction: a magnetic field, a conductor and relative motion between the field and conductor. Relative motion means that either: the conductor is moving through the magnetic field; or the field is moving across the conductor.

4-4. Let us discuss some of the other terms that we will encounter in dealing with inductance. Figure 4-1 shows only one conductor, and the CEMF is induced in this conductor. This is SELF-INDUCTION. Self-induction is defined as the process by which the magnetic field of a conductor induces a CEMF in the conductor itself. The symbol for self-induction is the same as the symbol for inductance; that is the letter "L".

4-5. Another type of induction is MUTUAL INDUCTION. Mutual induction is defined as the action of inducing a voltage in one circuit by varying the current in some other circuit.

4-6. In figure 4-2, a second coil is placed within the range of the expanding and collapsing field of the first coil. The moving magnetic field around coil A cuts across coil B inducing a voltage across coil B which causes a current to flow in the voltmeter. This effect between two inductances is called MUTUAL INDUCTION and the inductance shared by the two coils is called their MUTUAL INDUCTANCE. Two circuits so placed that energy is transferred by magnetic linkage and having no physical connection between coils, is said to be inductively coupled. The symbol for mutual inductance is the letter M and the unit of measure is the henry (H).

4-7. Each time the magnetic field builds up or collapses, it cuts across coil B. Here we have the three requirements for induction: a magnetic field, a conductor, and relative motion. The phase relations of current and voltage in the two windings are such that the polarity of the voltage induced in coil B will always set up a current, the magnetic field of which will oppose or be 180 degrees out of phase with the inducing field of coil A. If both coils A and B are

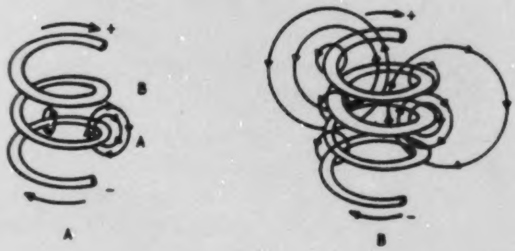

Figure 4-1. Self Induction

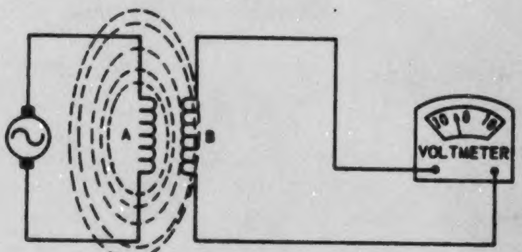

Figure 4-2. Mutual Induction

wound in the same direction on an iron core, whenever the top of coil A is positive the top of coil B will be negative. Normally this phase reversal will take place.

4-8. The unit of measure for inductance is the HENRY. A henry is defined as: The inductance in a circuit which induces an EMF of one volt when the current is changing at a rate of one ampere per second. The symbol for henry is H.

4-9. Closely associated with induction is flux linkage. Flux linkage is defined as the interlocking of magnetic lines of force; it is the number of these flux linkages within a coil that determines the inductance of a coil.

4-10. Figure 4-3 symbolizes flux linkage. The coils shown in figure 4-3A have a smaller amount of flux linkage than the coils shown in figure 4-3B. Notice that few lines of force from coil 1 link coil 2 in figure 4-3A, while many lines of force from coil 3 link coil 4 in figure 4-3B. The ratio of the number of flux lines that cut a second coil to the total number of flux lines that originate in the first coil is called COEFFICIENT OF COUPLING. Coefficient of coupling is explained later in this chapter.

4-11. A transformer is a device that transfers electrical energy from one circuit to another by electromagnetic induction. The energy is always transferred without change in frequency but usually involves changes in voltage and current. Because transformers work on the principle of induction, they must use a changing current source to supply a continuous output. A simple transformer consists of coils of wire placed on some type of core.

4-12. SCHEMATIC SYMBOL. A basic transformer symbol looks like two coils as shown in figure 4-4A. The winding that is connected to the source is called the PRIMARY winding. The winding that supplies energy to the load is called the SECONDARY winding. A transformer may have several secondary windings, figure 4-4B. Frequently, additional connections are made to a transformer winding between the end connections. These additional connections are called taps, figure 4-4C. A tap placed at the center of a winding is called a center tap, figure 4-4D. The SENSE DOTS (·) shown in figure 4-4E and 4-4F indicate the ends of the windings which have the same polarity at the same instant of time. If sense dots are not used, a phase reversal of 180° is assumed.

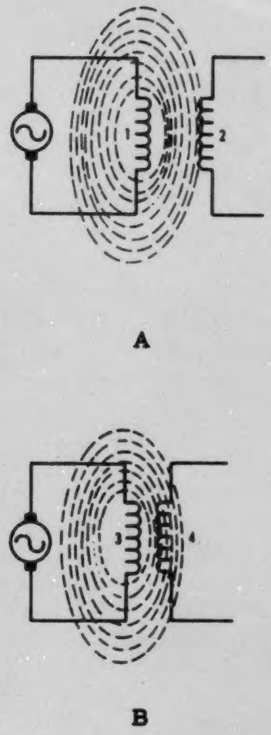

Figure 4-3. Coefficient of Coupling

> NOTE. The phase of the output voltage may be reversed by reversing the leads of the primary or secondary coil.

4-13. CORE. Just as an inductor has either an iron core or an air core, figure 4-5, a transformer usually has an air core or some form of an iron core. Figure 4-5 shows the schematic representation. The windings are positioned so that the flux lines of one inductor cuts the other inductor. The air core transformer is commonly used in circuits carrying radio-frequency energy. Radio-frequency transformers also use powdered iron, brass, and aluminum cores. Transformers used in

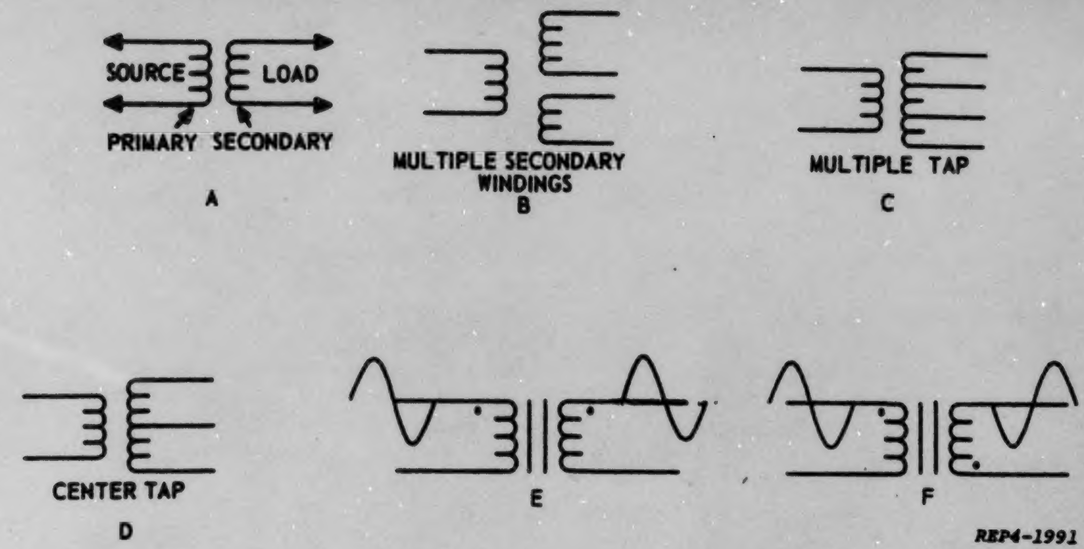

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Figure 4-4. Transformer Schematic Symbols

low-frequency circuits require a core of low-reluctance magnetic material to concentrate the field about the windings. This type of transformer is called an iron-core transformer; audio and power transformers are of the iron-core type.

4-14. Transformer Action. For principles of transformer action, use the simplified diagrams of figure 4-6. The transformer of figure 4-6A consists of a 10-turn primary winding and a 2-turn secondary winding. The ratio of the number of turns in the primary to the turns in the secondary is called the TURNS RATIO. The turns ratio pertains to the step-up or step-down ratio from primary to secondary.

4-15. If an AC input is applied to the primary winding and no load is connected to the secondary winding, the primary acts as a simple inductor. The current flowing in the primary will depend on the amplitude of the applied voltage and the inductive reactance of the primary. This current produces a magnetic field which cuts the primary and secondary as it expands and collapses. This produces a CEMF in the primary (self-inductance), which nearly equals the applied voltage; and induces a voltage in the secondary (mutual inductance). The amplitude of

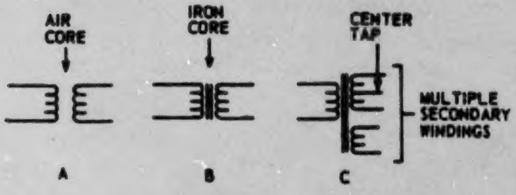

Figure 4-5. Core Types

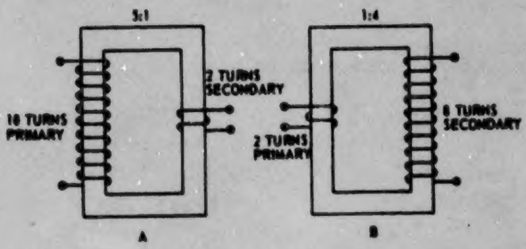

Figure 4-6. Turns Ratio Comparison

the voltage induced into each turn of the secondary will be identical to the CEMF produced in each turn of the primary.

4-16. With 10 volts applied across ten turns, there will be developed a counter EMF of nearly 1 volt per turn. A 2-turn secondary will then have an induced voltage of 2 volts (1 volt per turn). Thus, a turns ratio of 10 (primary) to 2 (secondary) has produced a step-down in voltage, from 10 volts (primary) to 2 volts (secondary). Thus, the transformer is described as being a step-down transformer.

4-17. Figure 4-6B shows a transformer with a step-up turns ratio of 1:4. An input of 10 volts applied to the primary will produce 40 volts in the secondary. Notice that the TURNS ratio equals the VOLTAGE ratio in all cases.

We can express this as an equation:

$$\frac{N_p}{N_s} = \frac{E_p}{E_s}$$

where:

N_p = number of turns in the primary.

N_s = number of turns in the secondary.

E_p = voltage of the primary.

E_s = voltage of the secondary.

4-18. The extent to which magnetic lines of the primary cut across the secondary is expressed as a COEFFICIENT OF COUPLING. We assumed the transformers in figure 4-6 had a coefficient of coupling of 1. This means that all of the magnetic lines of the primary link the secondary. That is, 100% of the flux lines produced by the primary winding cut the secondary winding. A coefficient of coupling of .9 indicates that 90% of the flux lines produced by the primary cut the secondary. A coefficient of coupling less than 1 reduces the voltage induced in the secondary.

4-19. Up to now, our discussion of the transformer action has been with no load on the secondary, we considered induced voltage only. The polarity of the induced voltage can be determined by the use of the left-hand rule. When a load is connected to the secondary winding of a transformer, current flows in the secondary. The magnetic field produced by current in the secondary interacts with the primary field. This interaction is truly mutual inductance, where both primary and secondary currents induce voltages. The magnetic field produced by secondary current is in direct opposition to the primary magnetic field, and cancels some of the primary field. This reduces primary CEMF, and, as a result, primary current increases. Therefore, as secondary current increases primary current increases.

4-20. Total power available from a transformer secondary must come from the source which supplied the primary. Remember, a transformer does not generate power, it merely transfers power from a primary circuit to a secondary circuit. If the transformer is 100% efficient, total primary power equals secondary power. Figure 4-7A shows a 100 Ω load connected to the secondary. The transformer has a step-up turns ratio of 1:10. Ten volts applied to the primary will produce 100 volts in the secondary. Current through the 100 Ω load will be 1 amp. Power consumed in the load is (I x E = P) 100 watts. This power must come from the source. The source must supply 10 amps at 10 volts (I x E = P) or 100 watts. Notice that we have a step-up in voltage (1:10) and a step-down in current (10:1). Power supplied to the LOAD comes from the SOURCE, and we have no losses in the coupling. This transformer is 100% efficient because output power equals input power.

4-21. Refer to figure 4-7B. The transformer has a step-down turns ratio of 5:1. Fifty volts applied to the primary will induce 10 volts in the secondary. If we use a 10 Ω load connected to the secondary, we will have 1 amp of current ($I_s = \frac{E}{R_s}$) and power consumed by the load is 10 watts (P = I x E). Now the source must supply 10 watts of power. With 50 volts, the current needed to provide this power is:

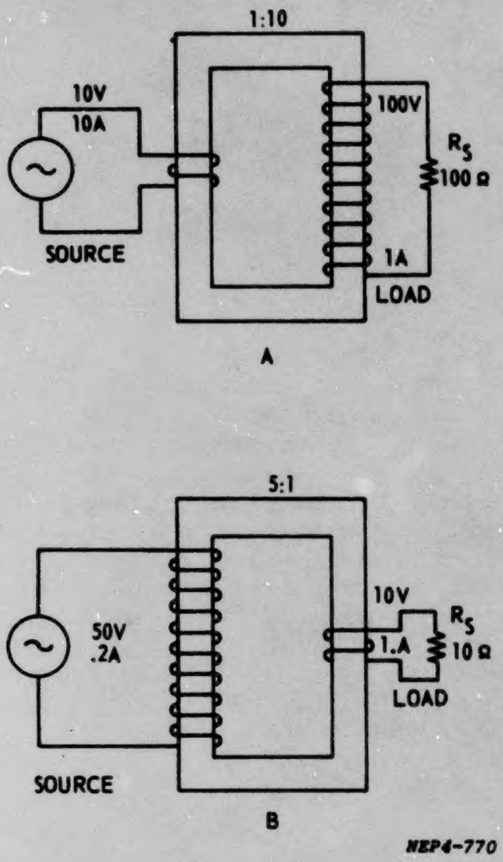

Figure 4-7. Reflected Impedance

$$I_p = \frac{P}{E_p}$$

$$I = \frac{10 \text{ watts}}{50 \text{ volts}}$$

$$I = \frac{1}{5} \text{ amp (0.2 amp)}$$

4-22. Notice that we have a step-down in voltage but a step-up in current. The current is increased by the same ratio as the voltage decrease. Again, our calculations assume a 100% efficient transformer. To our turns-voltage ratio $\left(\frac{N_p}{N_s} = \frac{E_p}{E_s}\right)$ we can add a current ratio:

$$\frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{I_s}{I_p}$$

where:

I_s = current in the secondary.

I_p = current in the primary.

Recall the axiom which states that "quantities equal to the same thing, are equal to each other." We can, therefore, use the above equation in three forms:

$$\frac{N_p}{N_s} = \frac{E_p}{E_s} \qquad \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

$$\frac{E_p}{E_s} = \frac{I_s}{I_p}$$

4-23. IMPEDANCE. In general, AC circuits consist of resistance and reactance. The lumped sum of these oppositions to AC current is called IMPEDANCE (Z). Because impedance is opposition to current flow, impedance is measured in Ohms (Ω). As the secondary impedance (Z_s) changes, the secondary current (I_s) changes. As explained earlier, a change in I_s causes a change in primary current (I_p). Ohm's law shows that this effects primary impedance (Z_p). $E_p = I_p \times Z_p$. Therefore, a change in Z_s will cause a change in Z_p. This action is called REFLECTED impedance. The following formulas show the inter-action between the source and the load:

$$\frac{Z_p}{Z_s} = \frac{I_s^2}{I_p^2} \qquad \frac{Z_p}{Z_s} = \frac{E_p^2}{E_s^2}$$

$$\frac{Z_p}{Z_s} = \frac{N_p^2}{N_s^2}$$

4-24. Practical transformers, although highly efficient, are not perfect devices. They range from 80 to 98 percent efficient. Primary power must be slightly greater than secondary power to offset the decrease in efficiency. The losses associated with transformers are the same as the losses for inductors. Efficiency can be computed by dividing transformer output power by input power.

4-25. Types of Transformers. In general, we have four types of transformers: autotransformers, power transformers, audio transformers, and RF transformers.

4-26. The autotransformer is a special type of transformer. By definition, it is a transformer with a single winding (electrically) which is tapped. The whole winding may be used as the primary and part as a secondary (step-down) or part of the winding may be used as the primary and all of the winding used as the secondary (step-up). Figure 4-8 shows the symbol and several possible connections. Notice, in all cases, that a complete DC circuit exists between primary and secondary.

4-27. Autotransformers may be used in power circuits, audio circuits, or RF circuits. Figure 4-8 shows the symbol for power and audio autotransformers. The symbol for an RF autotransformer is the same except that it often has an air core.

4-28. Power transformers are often constructed with two or more secondary windings. Thus, one transformer can provide several voltage level outputs. The schematic in figure 4-9 is an example of a typical power transformer. The secondaries provide a wide selection of voltages and currents. Power transformers are designed to operate on the common power line frequencies (50 to 1600 Hz) and to handle relatively large amounts of power.

PRIMARY	SECONDARY	
	STEP UP	STEP DOWN
1-2	1-3	2-3
1-3	-	1-2 2-3
2-3	1-3 1-2	

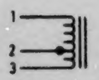

Figure 4-8. Autotransformer

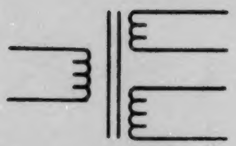

Figure 4-9. Power Transformer

4-29. The audio transformer resembles a power transformer in appearance; however, it has several internal refinements. The core material is carefully selected and special techniques are used to fabricate the windings. Audio transformers are designed to operate over the audio range of 20-20,000 Hz. Audio transformers are available with multiple primaries and/or secondaries.

4-30. The RF transformer is used for frequencies above the audio range. The symbol for an air-core RF transformer is shown in figure 4-10.

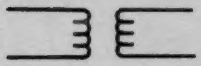

Figure 4-10. RF Transformer

4-31. Troubleshooting Transformers. There are times, when you are troubleshooting a system, that you may want to check a transformer for opens or shorts, or you may want to determine whether a transformer steps up or steps down the voltage. Let's first see how to check a transformer for an open or short.

4-32. An open winding in a transformer is located by connecting an ohmmeter, as shown in figure 4-11A--the ohmmeter reads infinity. The reading on a good winding should be the resistance of the winding. Both the primary and secondary windings may be checked in this manner. (Observe that, when using the ohmmeter, no power is applied and the circuit component is isolated.)

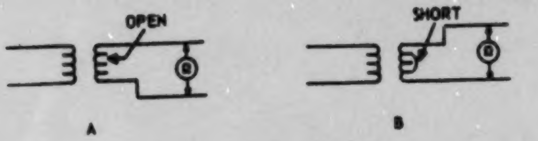

Figure 4-11. Transformer Malfunctions

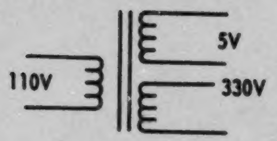

Figure 4-12. Power Transformer

4-33. The ohmmeter may also be used to check for a shorted winding, as shown in figure 4-11B. However, this method is not always accurate. For example, suppose a transformer winding has 500 turns and a resistance of 2 ohms and 5 turns were shorted out. This would reduce the resistance of the winding to 1.98 ohms--not enough difference to be read on an ohmmeter. The best way to check the transformer for shorted windings is to apply the rated input voltage to the primary and measure the output voltage of the secondary. If the output voltage is low, you can assume that the transformer has some shorted windings.

4-34. Earlier in this lesson we learned that the turns ratio determined whether the voltage was stepped-up or stepped-down and by what amount. Let's look at figure 4-12. The primary has 110 volts applied, one secondary has a 5 volt output while the other secondary has a 330 volt output. Assuming a coefficient of coupling of 1.0, the turns would be 22 to 1 for the 5 volt secondary and 1 to 3 for the 330 volt secondary. Let's further assume that the transformer has a 220 turn primary, 10 turn (5 volt) secondary. The 5 volt winding, since it has the least number of turns, will have the smallest resistance, and the 330 volt secondary (with 660 turns) will have the largest resistance. This shows how you can use resistance readings to determine whether a transformer has a step-up or step-down turns ratio. In a step-down transformer, the resistance of the secondary will be less than that of the primary. In a step-up transformer, the secondary will have the higher resistance.

4-35. Another way to determine whether a transformer has a step-up or step-down turns ratio is to apply a voltage to the primary and measure the output of the secondary. When checking a transformer in this manner, be sure that you do not apply voltages that exceed the rating of the transformer or of the meter. Figure 4-13A shows a transformer with a 10 volt input and a 50 volt output. This indicates that the transformer has a step-up ratio of 1 to 5. Figure 4-13B shows a transformer with 10 volts applied to the primary and a voltmeter reading of 2 volts across the secondary, indicating a 5 to 1 step-down transformer.

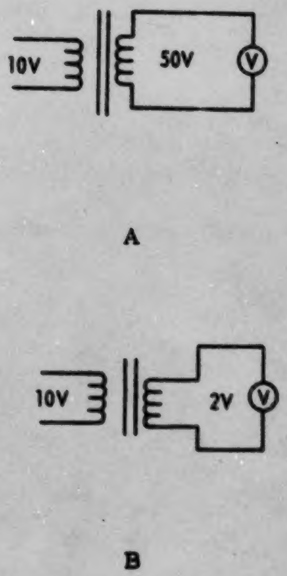

Figure 4-13. Step-up and Step-down Transformers

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Chapter 5

ELECTROMECHANICAL DEVICES

5-1. Electromechanical devices are devices that use electromagnetism to operate. One of the simplest devices that falls in this group is the relay. Relays use the magnetic effect produced when a current is applied to a coil to attract an iron bar. This iron bar opens or closes other circuits. The electromechanical devices which will be explained in this chapter are: relays, microphones, speakers, meter movements, motors, and generators.

5-2. Electromagnetic Relay.

5-3. While relays are made in many different sizes and shapes and are used for many different purposes, all electromagnetic relays operate on the principle that iron is attracted to a pole of an electromagnet. A relay consists essentially of a coil with an iron core and movable iron bar. When current flows in the coil, electromagnetism pulls the movable bar toward the core. The movement of the bar opens or closes a circuit. The relay is usually referred to as a remote control switch because it can control the operation of other circuits without being in the same area.

5-4. Figure 5-1 shows a basic relay and relay circuit. The relay itself consists of five main parts: core, coil, armature, contacts, and spring. When switch S is closed, current flows through the coil and causes a strong magnetic field to be set up around the coil. This magnetic field pulls the armature toward the core of the coil, causing the contact points to close; this completes a path for current in the lamp circuit. Closing the relay circuit controls the lamp circuit, and the lamp glows. When switch S is opened, the field about the electomagnet collapses; the spring pulls the armature contacts apart and the lamp circuit opens.

5-5. Electromagnetic relays may be represented by a schematic diagram, rather than the pictorial illustration of mechanical components used in figure 5-1. Figure 5-2A shows a single pole, single throw (SPST) relay with the contacts in the normally open (N.O.) position. When current flows through the coil, the contacts close. Figure 5-2B shows a SPST relay with the contacts normally closed (N.C.) When current flows through the coil, the contacts open. Figure 5-2C shows a single pole, double throw (SPDT) relay. This type of relay is used to transfer a circuit function from one condition to another condition.

5-6. Note the relays shown in figure 5-2 are in the deenergized position; no current is flowing through the coil. In all schematic diagrams the relays are deenergized unless otherwise stated.

5-7. Relay Circuits.

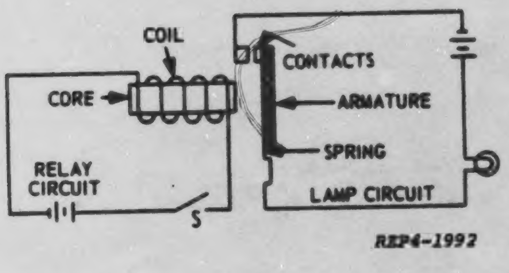


Figure 5-1. Relay Circuit

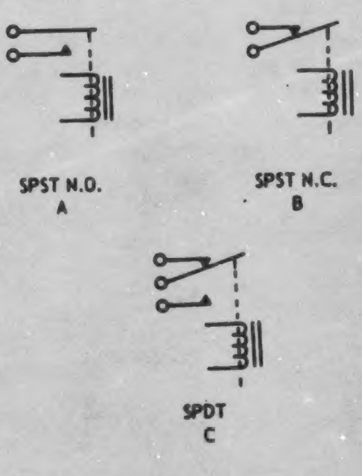


Figure 5-2. Relay Symbols

5-8. **Holding Relay.** Figure 5-3 shows a holding relay circuit. The closing of switch S2 will permit current to flow in coil C. The contact arm (which contains iron) will be attracted toward the upper end of the electromagnet, thus closing the circuit at A. This permits a complete path for current in coil C and in the lamp circuit. The lamp will glow. Now opening the switch S2 will not open the coil or lamp circuit. In order to do this, switch S1 must be opened. This is the action of a HOLDING RELAY.

5-9. **Remote Control or Starting Relay.** A common use of the relay is in an automobile starter circuit. The ignition switch on the instrument panel activates a relay which, upon closing, permits high current to flow in the starter motor circuit. The starter armature rotates and by a gear arrangement rotates the crankshaft. Figure 5-4 shows the switching arrangement.

5-10. When the ignition switch closes the relay coil circuit, current flows in the coil. The many turns of wire that form the coil offer enough resistance to limit the current to a fraction of an ampere even though the coil is connected directly across the battery. This current causes an electromagnetic force which pulls the iron bar B toward the coil and closes the starter motor circuit. Note that the conductors in this circuit are short, heavy cables. The large size of the cables and their short length decreases the I^2R loss. The expense and weight of a starter circuit which routes the heavy current through the switch on the instrument panel is prohibitive. A small current in the relay coil circuit can control a very large current in the starter circuit.

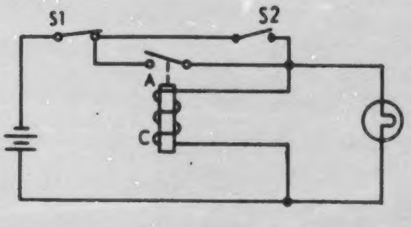


Figure 5-3. Holding Relay

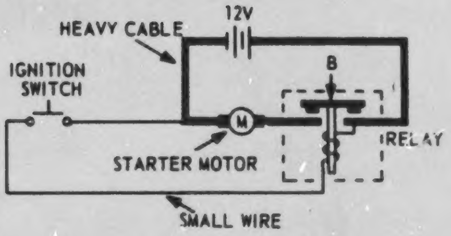


Figure 5-4. Starter Relay

5-11. **Overload Relay.** Another application of an electromagnetic relay is its use as a protective device, similar to a fuse. Refer to figure 5-5. When switch S is closed, current flows through the relay coil and load resistor (R_L). Let us assume normal circuit current is 10 mA. Let us also assume the relay requires 20 mA of current to flow through the coil before it will energize. Suppose the load resistor partially shorts out causing the circuit current to exceed 20 mA. As soon as 20 mA of current flows through the relay coil, the relay will energize and interrupt the path for current. Once energized, the latch will lock in the open position. After the trouble has been corrected, the reset button can be pushed to unlock the armature. It then returns to its N.C. position. The action of the relay described here is that of an OVERLOAD relay with manual reset. More elaborate overload relay circuits often use an automatic reset feature.

5-12. In electronic systems many different types of relays are used. Not all of them, by any means, are employed for remote control switching. Regardless of their purpose, the principle of operation is the same: A current through a coil creates

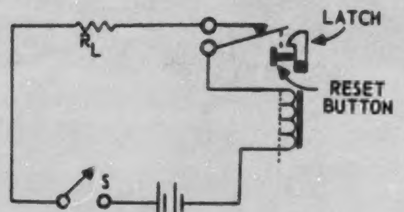


Figure 5-5. Overload Relay

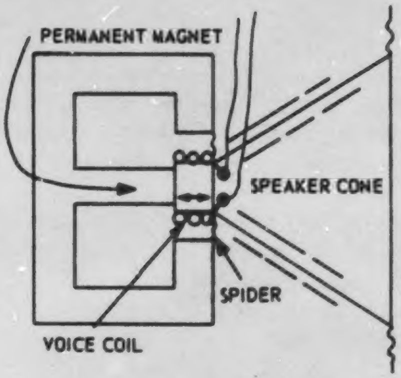


Figure 5-6. Permanent Magnet Speaker

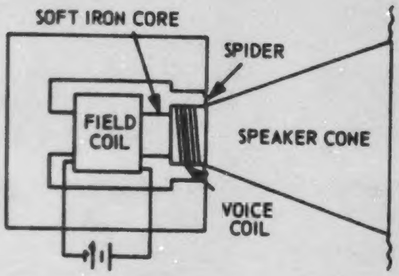


Figure 5-7. Electromagnetic Speaker

an electromagnet which causes the movement of an iron bar. This movement of the bar causes another circuit to close or open.

5-13. Care of Relays. A relay should be inspected and checked thoroughly and frequently to insure troublefree operation. Make a visual check of the contacts using a magnifying glass. If the inspection reveals an oxide coating or carbon deposit, use a relay burnishing tool to wipe the contacts clean. Never file the contacts. Check armature spring tension. A weak spring or improper adjustment of spring tension could cause the relay to chatter. Check the relay coil for signs of overheating. A partially shorted coil could cause chatter, hum, or reduced magnetic pulling power. An open coil would result in the relay's failure to energize. When in doubt as to the electrical continuity of the coil, check its resistance with an ohmmeter and compare measured reading against the manufacturer's specified value. Following good preventive maintenance techniques will assure relay reliability.

5-14. Loudspeakers.

5-15. The loudspeaker is a device which converts electrical energy to sound energy (sound waves). They will be found in radios, televisions, stereos, public address systems, and other places. Loudspeakers of various types and with different design characteristics are used in a variety of applications.

5-16. Dynamic Loudspeaker. The speaker most commonly used in present day radio receivers and phonographs is the permanent-magnet dynamic (or moving coil) speaker. The permanent-magnet dynamic speaker is referred to as a PM speaker.

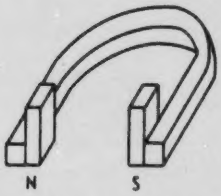
5-17. The dynamic speaker in figure 5-6 uses a small coil, called the voice coil, wound on a cylinder of bakelite or fiber material. The voice coil is mounted so that it is able to move back and forth. The voice coil is centered around the pole piece by a very flexible, springy material called a spider. The spider is also attached directly to the paper cone. Audio frequency variations of current passing through the voice coil produce a varying magnetic field which interacts with the magnetic field of the speaker magnet. The interaction of the magnetic fields cause motion of the voice coil. Since the speaker cone is directly connected to the voice coil, its motion corresponds to that of the voice coil. This movement will disturb the air and produce sound waves directly related to the audio signals applied to the voice coil.

5-18. The electromagnetic dynamic loudspeaker is the same as the permanent-magnet dynamic loudspeaker except the permanent-magnet is replaced with an electromagnet (field coil), as shown in figure 5-7.

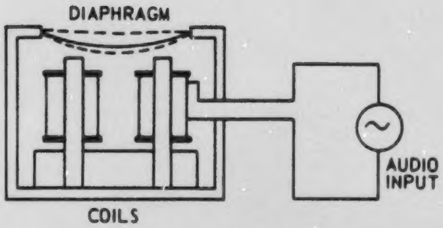
5-19. To achieve good tonal quality the loudspeaker must have a good frequency response. It must reproduce all frequencies in the audio range. Some of the factors which affect the frequency response are the cone size, material, shape, and enclosure.

5-20. Earphones. The operation of the earphone causes a diaphragm of metal, paper, or fiber to vibrate at an audio frequency rate and produce sound. The earphone shown in figure 5-8 shows how a diaphragm is made to vibrate. The phone comprises a horseshoe-shaped permanent magnet with two pole pieces as shown in figure 5-8A. Two coils, a vibrating metal diaphragm, and an enclosure complete the earphone. A cross-sectional view is shown in figure 5-8B.

5-21. With no current in the coils, the magnetic field between the poles holds the metal diaphragm in the position shown by the solid line. When current passes through the coils, it causes a magnetic field which aids or opposes the magnetic field of the permanent magnet. This increase or decrease in the magnetic field varies the tension on the diaphragm. An alternating current applied to the coils causes the diaphragm to vibrate at the frequency of the applied current and generate a sound wave.



A. Permanent Magnet with Pole Pieces



B. Basic Design of Earphone

Figure 5-8. Earphone

5-22. Microphones.

5-23. There are many different types of microphones, but all have certain characteristics in common. They are electro-acoustic transducers that convert sound energy (sound waves) into electrical energy.

5-24. The type of microphones or electro-acoustic transducers that will be discussed are the carbon microphone, the capacitor microphone, the crystal microphone, dynamic microphone, and the velocity ribbon microphone.

5-25. Carbon Microphones. The carbon microphone operates on the principle of varying the resistance of granules of powdered carbon by varying the pressure on them. When the granules are compressed (close together), the electrical resistance decreases. The sound waves strike a metal diaphragm, causing it to vibrate at an audio rate. The diaphragm is attached to a metal pin, as shown in figure 5-9A. This pin comes in contact with the carbon granules and causes them to alternately come closer together and farther apart. This varying resistance causes the current to increase and decrease at an audio rate, as shown in figure 5-9B.

5-26. The frequency response for the carbon microphone is poor. The response is good for the reproduction of the human voice, but is too limited for good reproduction of music. The carbon microphone is inexpensive rugged, and highly reliable.

5-27. Capacitor Microphones. The capacitor microphone consists of a metal backing plate, with a thin metal diaphragm set close

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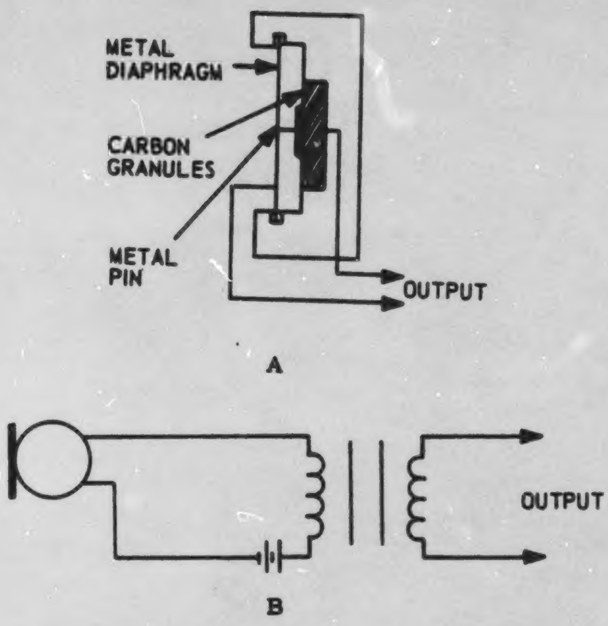


Figure 5-9. Carbon Microphone

to it, as shown in figure 5-10A. The backing plate and the diaphragm form the plates of a capacitor. The sound waves cause the diaphragm to vibrate, varying the distance between it and the plate. These changes in spacing cause changes in the capacitance. This changing capacitance is placed in a series circuit and causes the current to change through the resistor, as shown in figure 5-10B.

5-28. The capacitor microphone has excellent frequency response and gives high quality reproduction to speech and music. However, it is extremely delicate and can be easily damaged by mechanical shock or high-intensity sound waves.

5-29. **Crystal Microphone.** The crystal microphone makes use of the piezoelectric effect. Certain crystalline structures, such as quartz and Rochelle salts, generate an electrical potential when they are made to bend. The polarity and amount of electric potential depends upon the direction and amount of mechanical pressure. The crystal microphone utilizes this potential.

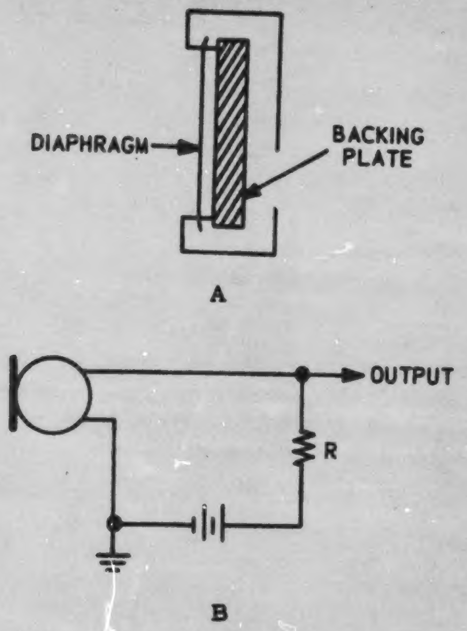


Figure 5-10. Capacitor Microphone

5-30. The basis of the crystal microphone is a pair of crystal slabs with foil bonded to each side. These are clamped together as shown in figure 5-11A. Figure 5-11B shows two pairs of crystal slabs mounted in series. The crystals are enclosed in a light membrane which protects them from dust and moisture. The sound waves cause the crystals to vibrate as shown by the dotted lines in the figure and produce alternating

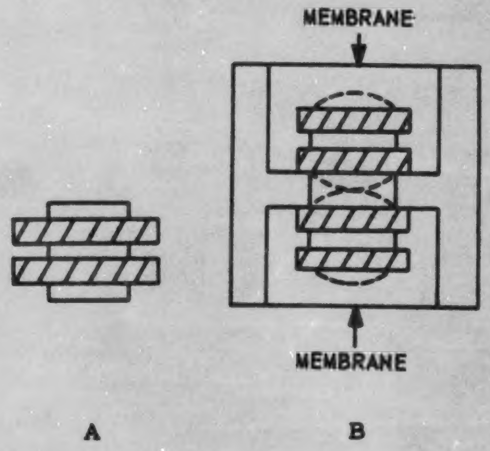


Figure 5-11. Crystal Microphone

current. This type of microphone has an excellent frequency response, is rugged and reliable, and requires no external power. It can be made extremely small and is generally found in portable sound systems.

5-31. **Dynamic Microphone.** The dynamic microphone makes use of the moving-coil principle used in the dynamic loudspeaker. Sound waves vibrate the diaphragm and cause the movable coil to move in a magnetic field. Movement of the coil in the magnetic field induces an alternating current in the coil at the frequency of vibration.

5-32. It will be recalled that the coil motion in a dynamic loudspeaker is produced by passing an alternating current through the movable voice coil, and that the motion is coupled to a diaphragm which generates sound waves. Therefore, many intercommunications sets use the same device as both a loudspeaker and a microphone, with the proper connections being made by means of a PUSH-TO-TALK button. However, a well designed dynamic microphone, as is illustrated in figure 5-12, is not usable as a loudspeaker.

5-33. **Velocity-Ribbon Microphone.** The velocity-ribbon microphone makes use of the current produced when a corrugated aluminum ribbon suspended in a strong magnetic field is caused to vibrate. Figure 5-13 illustrates the construction of such a microphone.

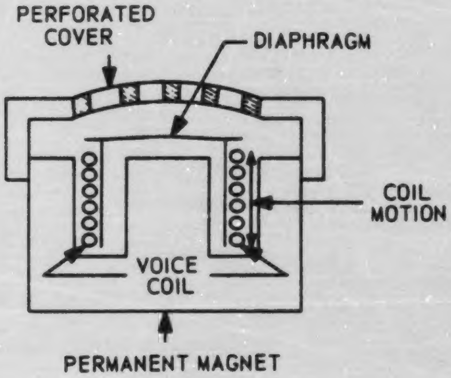
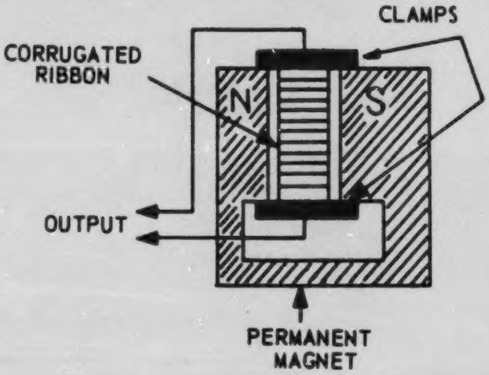
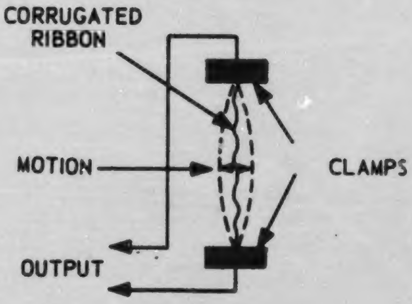


Figure 5-12. Dynamic Microphone



Front View



Side View

Figure 5-13. Velocity Ribbon Microphone

5-34. The operation of the velocity-ribbon microphone is essentially the same as that of the dynamic microphone. Sound waves cause the aluminum ribbon to vibrate in the strong magnetic field and induces an electric current in the ribbon. The amplitude of the current depends on the velocity at which the ribbon moves through the field, which varies with the volume of the sound.

5-35. The velocity-ribbon microphone is a fairly rugged device which reproduces speech and music of good quality and needs no external power. It is highly directional, an important advantage where the pick-up of surrounding noise is undesirable.

5-36. **Meter Movements and Circuits.**

5-37. You already know that meters are used to measure electrical quantities. You have used a multimeter which measures voltage, current, and resistance; its operation depends on the passage of an electric current through it. Your multimeter movement has its circuit designed and the scales calibrated to measure various values of the three basic electrical units: volts, ohms, and amps. Three classes of meters use electromagnetism: moving-iron meters, moving-coil meters, and dynamometers. When current flows through a coil, it produces a magnetic field which is directly proportional to the amount of current. The strength of this field can be used to indicate the amount of current passing through the coil. The moving-coil meter is the most popular type meter movement used today.

5-38. Moving-Coil Meter. The meter movement most commonly used in electronics is the permanent magnet moving coil, preferred because of its accuracy, ruggedness, and linear scale. In 1882, Arsene d'Arsonval, using the moving-coil principle, developed a galvanometer. In 1888, Dr. Edward Weston modified the design to make the meter easily portable. The basic movement still is referred to as the d'Arsonval movement.

5-39. Figure 5-14 illustrates the component units of a permanent magnet moving-coil meter movement. The permanent magnet, which is horseshoe-shaped, is made of a high permeability alloy such as alnico. The permanent magnet is terminated by pole pieces, which are constructed of soft iron to intensify the flux in the required region. The moving coil consists of many turns of fine copper wire wound around an aluminum bobbin, positioned in the magnetic field between the pole pieces. The current to be measured, or a predetermined portion of it, passes through this coil. This current makes an electromagnet which reacts with the permanent magnet's lines of force, and the bobbin moves. Attached to the aluminum bobbin is a pointer, and the moving bobbin causes the pointer of the meter to move. Retaining pins limit needle movement.

5-40. Due to its own momentum, the pointer could oscillate rather than stop at the proper position. The movement of the aluminum bobbin through the magnetic field however, induces currents in the bobbin which produce a torque on the bobbin that opposes the oscillations. Two spiral springs cause the needle of the meter to return to zero when no current flows through the moving coil; they also provide a path for current into and out of the coil. The electromagnet resulting from coil current must have the proper polarity to deflect the pointer from left to right. Reversing the current through the coil sets up a reverse polarity, and the needle PEGS against the left retaining pin. This can bend the needle, which will cause incorrect readings and permanent damage to the meter.

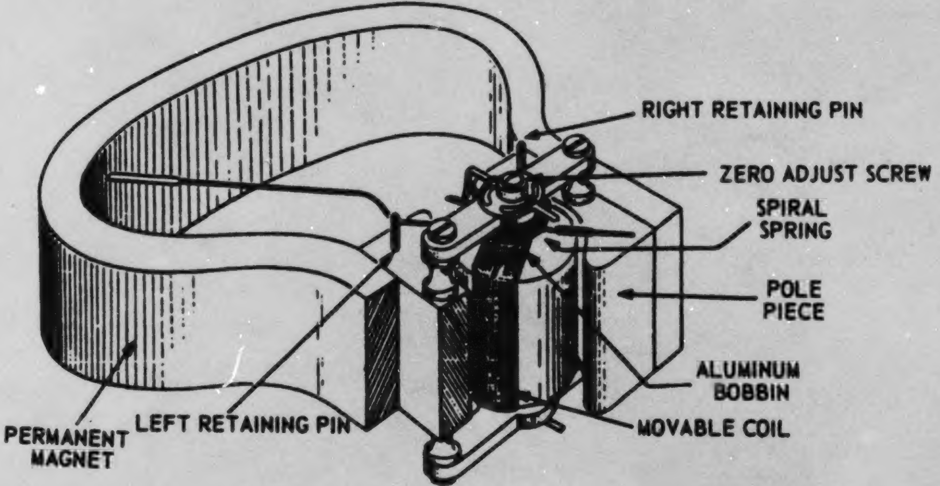
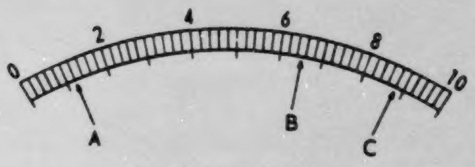


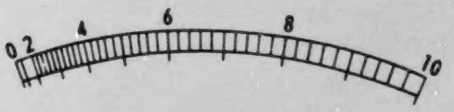
Figure 5-14. Meter Movement

5-41. Most moving-coil meters used for DC measurements have a linear scale, with equal spaces between the numbers, similar to the one shown in figure 5-15A. The amount of deflection is directly proportional to the amount of current flowing through the coil. When the rated current flows through the meter, the pointer deflection is full-scale. When half the rated current flows through the coil, the pointer deflection is half-scale, and so on. For example, point A on the scale corresponds to a reading of 1.2, point B reads 6.5, and point C reads 8.8. Compare the linear scale to the square-law scale shown in figure 5-15B.

5-42. Figure 5-16 illustrates a moving-coil meter movement schematic symbol. When current flows through the coil, it rotates causing the pointer attached to the coil to move across the scale. The amount of current required to move the needle from zero to full-scale deflection (FSD) is a measure of meter SENSITIVITY. The less current required to move a pointer to full-scale deflection, the greater the meter sensitivity. Meter sensitivity is expressed in milliamps or microamps. For example, if 50 microamps of current flowing through the meter coil causes full-scale deflection, then the sensitivity of the meter movement is 50 microamps. Once a meter movement has been manufactured with a given sensitivity, it cannot be changed.



A. Linear Scale



B. Square-law Scale

Figure 5-15. Meter Scales

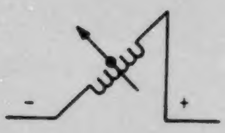


Figure 5-16. Meter Coil

5-43. A single meter movement can be connected as an ammeter, a voltmeter or, an ohmmeter. Each of these, in turn, can have multiple ranges of operation.

5-44. Ammeter. In the ammeter, the movable coil has a very low resistance, and the voltage drop across it is small. YOU MUST NEVER USE THIS METER IN A CIRCUIT WHERE THE CURRENT MAY EXCEED THE METER RANGE.

5-45. The range of an ammeter may be increased by placing a shunt resistance in parallel with the moving coil of the meter movement. This resistance, R_s, in figure 5-17, allows shunt current, I_s, to bypass the meter movement. The following example will show how the shunt resistance increases the range of the ammeter.

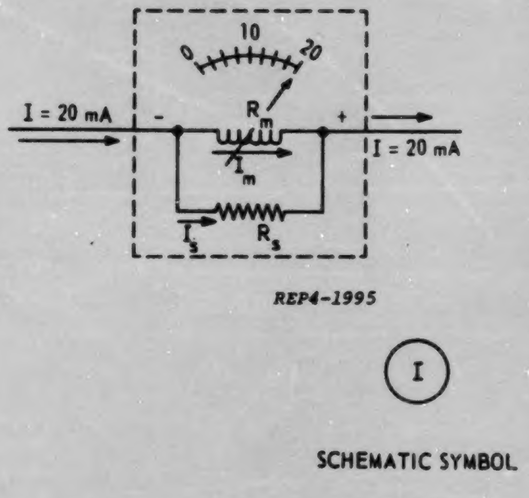


Figure 5-17. Current Meter

5-46. **EXAMPLE**: In the meter movement of figure 5-17, full-scale deflection of the needle occurs when 2 mA flows in the movable coil. The resistance R_m of the coil is 50 ohms. What must be the value of R_s to indicate a full scale current reading of 20 mA?

SOLUTION: Since only 2 mA of current in the coil is needed to cause full-scale deflection, 18 mA must be shunted around the coil through R_s. The voltage drops across the meter coil and across the shunt resistor are equal since the coil and the shunt are in parallel. The voltage drop across the coil is I_mR_m and across the resistor I_sR_s. Therefore,

$$I_sR_s = I_mR_m$$

$$R_s = \frac{I_mR_m}{I_s}$$

Since I_m, for full-scale deflection, is 2 mA, R_m is 50 ohms, and I_s is 18 mA, then, by substitution,

$$R_s = \frac{(0.002\ )(50)}{0.018} = 5.56\,\Omega$$

5-47. Note that the scale on the meter movement shown in figure 5-17 is calibrated to read 0 to 20. When the pointer is deflected to 20, I_m is 2 mA and I_s is 18 mA, and total current flow is 20 mA. The important point to realize is that only part of the total current flows through the moving coil. The remaining current flows through the shunt resistor. Using this method of dividing the current between the moving coil and shunt resistor makes it possible to change shunt resistors and recalibrate the scale to read any value of current.

5-48. Let's change the range of operation; suppose we want this meter movement to measure 50 mA. Full-scale deflection occurs with 2 mA, so 48 mA must go through the shunt. With 50 ohms resistance, the voltage drop across the meter movement is 0.1V; this same voltage drop is across the shunt which carries 48 mA. The resistance of the shunt, therefore, $= \frac{0.1\text{V}}{48\text{ mA}} = 2.08$ ohms.

5-49. Observe the difference in resistance values of the meter movement and the shunt: The shunt, which must carry much more current, has much less resistance.

5-50. Keep in mind that full-scale deflection occurs with very small current through the meter movement. Any greater current will damage or destroy the meter movement. ALWAYS make sure the ammeter is connected in series with the circuit and that the current to be measured is not greater than the maximum range that you have selected on the meter.

5-51. Voltmeter. In the voltmeter, the movable coil is connected in series with a resistance so that you may connect the instrument directly across a battery or generator and yet have only a small current flow through the meter. A voltmeter has this very high resistance to limit current flow from the circuit to which it is connected. You must exercise care to insure that you do not apply potential differences which exceed the range of the meter.

5-52. You may extend the range of a voltmeter by the use of additional series resistors. Such additional resistors are called multipliers.

5-53. **EXAMPLE**: A voltmeter having a moving-coil resistance of 50 ohms deflects full-scale when 2 mA flows in the coil. Find what resistance must be connected in series with the coil if the needle is to deflect full-scale when 200 volts is applied to the voltmeter.

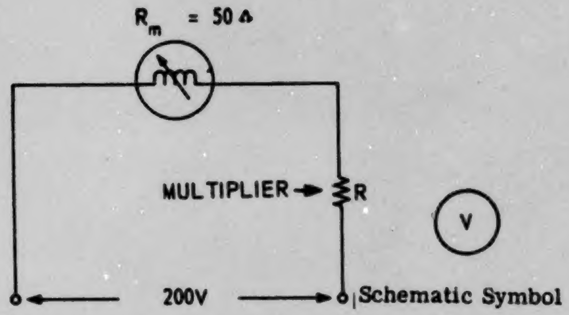


Figure 5-18. Voltmeter

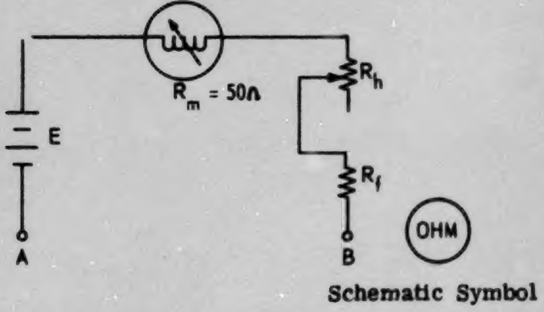


Figure 5-19. Ohmmeter

SOLUTION: Since the current is the same in the moving coil and the multiplier resistor (see figure 5-18), the total resistance of the circuit must be:

$$R = \frac{E}{I} = \frac{200}{0.002} = 100{,}000\,\Omega$$

Since the moving coil has a resistance of 50 ohms, the multiplier (series) resistor must have a value of 100,000 - 50 = 99,950 Ω.

5-54. To convert this same meter movement to read 10 volts, the series resistance must be changed to allow full-scale deflection when the voltmeter is across a 10-volt potential. Total $R = \frac{10\text{ V}}{2\text{ mA}}$ = 5000 ohms. Since the meter movement has 50 ohms resistance, the series multiplier will be 5000 - 50 = 4950 ohms.

5-55. Consider what would happen if the 10-volt meter were connected across 200 volts. Excessive current would destroy the meter. ALWAYS make sure the voltmeter range is large enough to protect the meter.

5-56. Voltmeter Sensitivity. We usually express the sensitivity of a voltmeter in ohms per volt. The range of the voltmeter in figure 5-18 is 200 volts. That is, when 200 volts is across the terminals of the voltmeter, the needle deflects fully to the right. The total resistance of the meter is 100,000 ohms. Therefore, the ohms-per-volt ratio or sensitivity is $\frac{100{,}000\,\Omega}{200\text{ V}}$ = 500 ohms per volt.

Since: $\frac{\text{volt}}{\text{ohms}}$ = amperes, then $\frac{\text{ohms}}{\text{volts}} = \frac{1}{\text{amperes}}$

Therefore, if you know the current necessary for full-scale deflection, you can determine the sensitivity of the meter in ohms per volt by finding the reciprocal of this current. For example, the voltmeter in figure 5-18 requires 2 mA for full-scale deflection. Therefore, its sensitivity in ohms per volt is $\frac{1}{0.002}$ = 500 ohms per volt.

5-57. We want to point out that this is not a sensitive instrument. An example of a sensitive voltmeter may be found in a popular and widely used meter in which the current necessary for full-scale deflection is 50 μA. The sensitivity of this meter is then:

$$\frac{1}{50\,\mu A} = \frac{1}{50 \times 10^{-6}} = 0.02 \times 10^{6} =$$

20,000 ohms per volt.

5-58. The accuracy of a voltmeter is determined by its sensitivity. Any meter which draws current from the circuit LOADS the circuit. Such circuit loading, more often called voltmeter loading, is undesirable. All moving coil meters draw current from the circuit under test. The higher the sensitivity, the lower the loading effect. The key, then, to accurate voltmeter readings is to have a voltmeter with a high ohms-per-volt ratio. This high ratio indicates a highly sensitive meter movement.

5-59. Ohmmeter. Not only do we use the basic meter movement as an ammeter and a voltmeter, but we also use it to measure resistance. In this case, the instrument is called an ohmmeter.

5-60. The simple ohmmeter circuit of figure 5-19 consists of the following elements: (1) a source of EMF usually supplied by a small dry cell, (2) a basic meter movement

R_m, (3) a variable resistance R_h (rheostat) for zeroing the meter, and (4) a fixed resistance R_f to limit the current flow.

5-61. If the dry-cell voltage is 1.5V, and 2 mA causes full-scale meter deflection, total series resistance must equal $\frac{1.5V}{2\ mA} = 750$ ohms. With this resistance and a good battery, connecting terminals A and B (figure 5-19) will cause full-scale deflection; this brings the needle to the zero ohms position (figure 5-20). As the battery gets old, it is necessary to adjust R_h (decrease the resistance) to ZERO the meter. If adjusting the meter cannot get the pointer to zero, you may need to replace the battery.

5-62. To measure the value of a resistor, first zero the meter, then place the resistor between the terminals A and B. The needle will not deflect full-scale, since now there is less current through the meter. As you insert greater and greater resistances, the needle will show less and less deflection. Finally, an open between terminals A and B will give no deflection of the needle.

5-63. The scale of this ohmmeter, instead of being numbered from left to right as are the scales on ammeters and voltmeters, is numbered from right to left as shown in figure 5-20. The scale results from the fact that current in a DC circuit with a constant applied voltage is inversely proportional to the resistance of the circuit. The scale is not linear nor is it a square-law scale.

5-64. Multimeter. You have studied the use of a multimeter. It combines the voltmeter, ohmmeter, and ammeter circuits by using switches. The multimeter uses only one basic meter movement. By proper selection of multipliers, shunts, limiting resistors, and batteries, the multimeter can serve as a voltmeter, ammeter, or ohmmeter with multiple ranges.

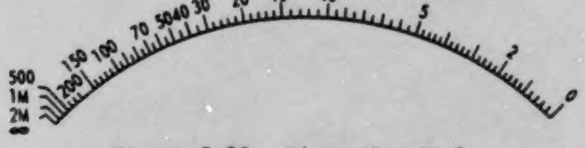


Figure 5-20. Ohmmeter Scale

5-65. It is important to remember that the moving coil type of voltmeter uses current from the circuit being tested. Placing the meter in the circuit can possibly change the measurement. The higher the meter sensitivity, the less current drawn and the more accurate the reading.

5-66. Basic Generator Concepts.

5-67. The requirements for magnetic induction were discussed earlier. They were: a conductor, a magnetic field and relative motion between the two. Before, the conductor remained stationary and the magnetic field expanded and collapsed across it. In the generator the conductor moves through the magnetic field to achieve relative motion.

5-68. Direction of Current Flow. Figure 5-21 shows a conductor moving downward through a stationary magnetic field with lines of force which go from left to right. Notice that we now have the three requirements necessary for induction. As the conductor moves down through the field, the field tends to encircle the conductor in a counter-clockwise direction. If we use the left-hand rule for a conductor, and place our fingers in the direction that the field encircles the conductor, our thumb will point in the direction of current flow. This rule, applied in figure 5-21, shows that the current in the conductor is flowing away from us (into the page) and is represented by placing an X or a + in the center of the conductor.

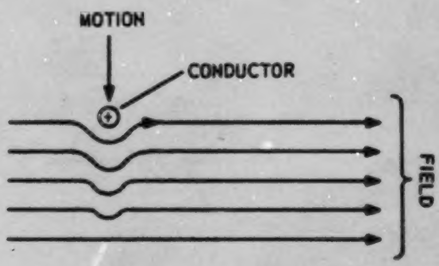


Figure 5-21. Magnetic Induction (Movement Down)

5-69. Now let's observe what happens when we move the conductor through the field in the opposite direction, as shown in figure 5-22. Applying the left-hand rule in figure 5-22, you can see that lines of force encircle the conductor in a clockwise direction. Therefore, the current is flowing toward you (out of the page); this is shown by the dot in the center of the conductor. From this discussion, we can see that a change in direction of relative motion produces a change in the direction of current flow in the conductor.

5-70. Magnitude of Induced Voltage.

5-71. The amount of the voltage induced into a conductor is dependent on the number of lines cut in a certain time (lines/unit of time). This is determined by four basic factors:

a. The speed of relative motion between the field and the conductor.

b. The strength of the magnetic field.

c. The length of the conductor within the field.

d. The angle at which the conductor cuts the field.

5-72. If the speed at which the conductor cuts the lines of force is increased, the force on the free electrons within the conductor is greater. This will increase the induced voltage.

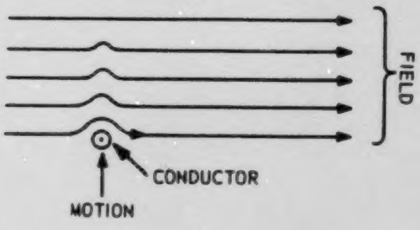


Figure 5-22. Magnetic Induction (Movement Up)

5-73. Increasing the strength of the magnetic field also increases the force on the electrons. The induced voltage is directly proportional to the strength of the field.

5-74. A long conductor permits the magnetic field to perform more work on the free electrons. If a number of short wires are connected in series, their voltages can be added. The armature of the generator uses this principle.

5-75. The angle at which the conductor cuts the lines of force affects the number of lines cut per unit time and, therefore, the amount of induced voltage. The generation of the sine wave was explained in an earlier module.

5-76. Components of a Basic AC Generator.

5-77. Refer to figure 5-23 which illustrates the components of a basic AC generator.

5-78. The pole pieces are the two ends of the magnet, and the field coil provides the magnetic lines of force at the pole pieces. The armature rotor is the part that rotates, and it includes slip rings and windings around a core. Not shown is the source of mechanical power which causes the armature to rotate. The slip rings are two metal rings mounted on the armature shaft, one ring for each end of the rotating conductor. The brushes are stationary contacts which ride on the slip rings to pick up the induced current and voltages.

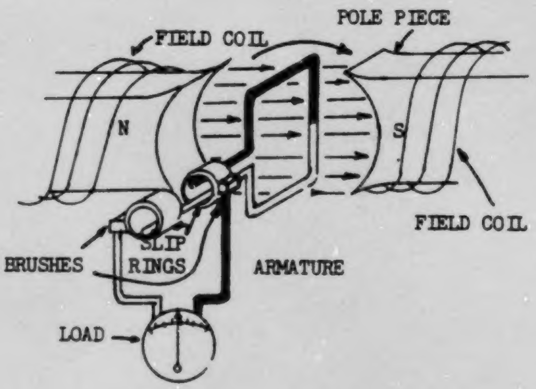


Figure 5-23. Basic AC Generator

5-79. Function of Components. Now that you are familiar with the components which make up a basic AC generator, let's study the function of each component. The pole pieces provide a path for the magnetic lines of force. They have curved faces to spread the flux uniformly across the space for the armature. In some cases, these pole pieces are permanent magnets; in other cases, electromagnets are used to provide the magnetic field. The generator is constructed so that the pole pieces and generator frame form a low-reluctance path for the magnetic field.

5-80. The rotating conductor is the winding on the armature core. The armature core provides a means of mounting and rotating the conductor, as well as providing a low-reluctance path between the pole pieces. As the conductor rotates in the magnetic field, it cuts magnetic lines of force. This action induces a voltage in the rotating conductor.

5-81. The slip rings rotate with the armature, while the brushes remain stationary and slide over the surface of the slip rings. This provides a means of applying the induced voltage from the rotating conductor to a stationary external circuit.

5-82. The external circuit and load provide a path in which the induced current flows so that useful work can be done. The load may consist of any device which conducts current, such as lamps, motors and transformers.

5-83. Components of a Basic DC Generator.

5-84. If you study figure 5-24, you will notice that the components of the basic DC generator are very similar to those of the basic AC generator. The only difference is the use of commutator segments rather than slip rings. The commutator segments provide a means of switching the connections to the external circuit each time the voltage induced in the armature changes polarity.

5-85. The pole pieces provide a path for the magnetic field. This magnetic field comes from either a permanent magnet or an electromagnet (formed by a field coil wound on the pole pieces). The armature provides a means of mounting and rotating the conductor within the magnetic field. The brushes provide a means of connecting the rotating electrical circuit of the armature with the stationary external circuits. Notice that both brushes ride on the same commutator; however, they are positioned so that they connect to opposite sides of the commutator. Look at the basic DC generator shown in figure 5-24 and see what type voltage it produces.

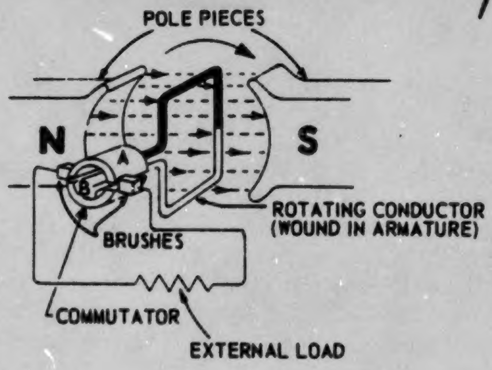


Figure 5-24. DC Generator (Minimum Induction)

5-86. How DC is Generated. The loop in figure 5-24 is shown in a position where the conductor is moving parallel to the magnetic field. At this position there is no voltage induced in the loop. Notice also that the brushes are across the openings between the commutator segments at this time. As the loop rotates through 90° from this position, a maximum voltage is induced in the conductor causing current to flow in the loop from A to B, as shown in figure 5-25. This causes current to flow out the left-hand brush, through the load in the direction indicated by the arrow, and back to the right-hand brush. When the loop reaches the 180° position, the induced voltage again becomes zero. Also, at this time the commutator has turned 180° and the brushes are across the openings.

5-87. As the loop rotates to the 270° position, a maximum voltage is induced in the loop causing a current flow within the loop from B to A. Because the left-hand brush is now riding on commutator segment A, current will flow out the left-hand brush, through the load in the direction indicated by the arrow, and back to the right-hand brush. Finally, as the loop continues to the 360° position, the induced voltage again returns to zero.

5-88. Types of Output. From this discussion you can see that, although the voltage induced in the loop reverses for every 180° rotation of the loop, the commutator switches the external circuit so that the current through the external circuit remains in the same direction. The voltage across the load is plotted in figure 5-26. When the loop is at 0° (figure 5-24), the voltage across the load is zero. When the loop is at 90° (figure 5-25), the voltage across the load is maximum. At 180°, the voltage again becomes zero; at 270°, the voltage is again maximum, and it returns to zero at 360°.

5-89. The voltage across the load does not reverse polarity; however, it varies from zero to maximum. This is a pulsating DC voltage as the DC output periodically drops to zero. Let us see how the DC output of the generator can be made smoother.

5-90. In figure 5-27, a second loop has been added to the generator. This loop is at 90° to the original loop. The commutator now has four segments. With an armature of this type, the induced voltage of one loop is at maximum while that in the other loop is at zero. If the brushes are positioned properly, they will furnish the maximum voltage to the external circuit during the time that each loop is at maximum. The output of a two-loop generator looks like that shown in figure 5-28. Practical DC generators have many loops so the output is much smoother. A filter placed across the output of the generator can further reduce ripple amplitude.

5-91. Motors

5-92. A motor is defined as a device which converts electrical energy into mechanical energy. The electrical energy develops magnetic fields which interact and exert a mechanical force. Motors come in many types and sizes to do all kinds of work. All motors operate on the same fundamental principle. A force is exerted between stationary and movable magnetic fields. The amount and direction of this force, which results from interactions of the two magnetic fields, determines motor speed and direction of rotation. In order to determine the amount of force and its direction, the strength and polarity of both magnetic fields must be known. Motors are normally classified according to the voltage or current used (AC or DC) and by the method of motor excitation.

5-93. Force Exerted Between Magnetic Fields.

5-94. Recall that a current-carrying conductor has a magnetic field. Polarity of the magnetic field depends upon the direction of the current. Figure 5-29 A & B illustrates the magnetic field around a conductor carrying current into and out of the page. A cross represents current flowing into the page and a dot represents current flowing out of the page. The field set up by current flow into the page is counterclockwise (CCW) and the field set up by current flow out of the page is clockwise (CW). Earlier in the course you used the "left-hand rule" to determine how lines of force move around a conductor. This rule states: "If you grasp a current-carrying conductor in the left hand with the thumb pointing in the direction of current flow, the fingers will point in the direction of the magnetic lines of force around the conductor."

5-95. When a current-carrying conductor is placed between the poles of the magnet as shown in figure 5-29A and 5-29B, interaction of the magnetic fields forces the conductor to move. Figure 5-29A shows the force which drives the conductor up and out of the field. Note that the magnet's lines of force below the conductor are in the same direction as the lines of force around the conductor. Recall that lines of force in the same direction repel each other. This repelling action forces the conductor upward. The conductor's lines of force above the conductor attract the stationary magnetic lines. This adds

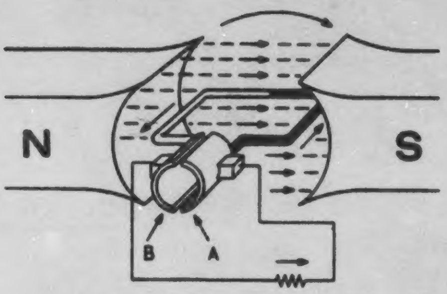


Figure 5-25. The Generator (Maximum Induction)

to the upward force on the conductor. The direction of the force is perpendicular to the stationary magnet's field.

5-96. Figure 5-29B shows the direction of current flow reversed; the direction of the force acting upon the conductor is also reversed. This condition forces the conductor to move downward.

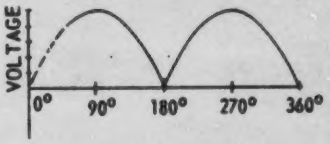


Figure 5-26. Induced Voltage

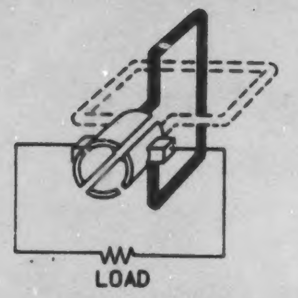


Figure 5-27. Two Loop DC Generator

5-97. Basic Direct-Current Motors.

5-98. Since we now know how a current-carrying conductor moves in a magnetic field, our next step is to determine how this action applies to a motor. A motor requires an internal turning force, which is called TORQUE. In a motor, the current-carrying conductor is formed into a coil and placed

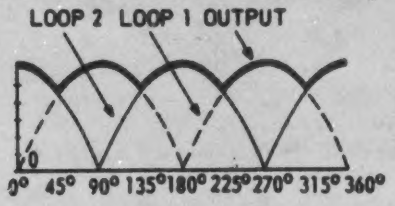
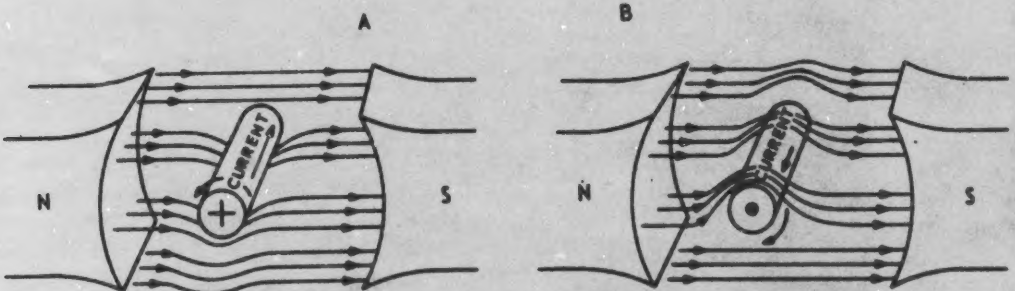


Figure 5-28. Output Waveform



CONDUCTOR MOVES UP

CONDUCTOR MOVES DOWN

Figure 5-29. How a Current-Carrying Conductor Moves in a Magnetic Field

on a shaft. The coil is free to rotate within the stationary magnetic field. The interactions of the permanent and rotating magnetic fields develop the torque which causes the shaft to turn. This torque also turns the external load on the motor.

5-99. Counter-Electromotive Force (CEMF).

5-100. The resistance of armature coils is very small, usually less than 1 ohm. If we assume .5 ohm of resistance with 100 volts applied, we would expect armature current to be 200 amps. This large current could destroy the motor. Actually, the armature current is much less than 200 amps due to a voltage induced in the armature as it moves within the magnetic field. This induced, EMF is 180° out of phase with the EMF applied to the armature and is called counter EMF (CEMF).

5-101. This induced voltage can be compared to the EMF produced by a generator. A generator converts mechanical energy into electrical energy, using a mechanical force to move a conductor. The polarity of the induced EMF is determined by Lenz's Law which may be stated as: "The current induced in a moving conductor is in a direction that opposes the motion which caused it."

5-102. AC Motors.

5-103. You are already familiar with the operation of DC motors which produce a torque by the interaction of two electromagnets. In AC motors the principles of rotating magnetic fields are used to produce torque. Consider first applying two phase AC power to a motor with two stator field windings as shown in figure 5-30A. Windings A and B are physically placed 90° apart. The rotor is a permanent magnet mounted on a shaft which is free to rotate.

5-104. At time T1 in figure 5-30B, phase A is maximum positive while phase B is zero. The magnetic field produced by the stator would be as in figure 5-30A. The rotor would point its north pole straight up (zero degrees). At time T2, note that the amplitude and polarity of the two phases are the same. This would produce a magnetic field as shown in figure 5-30C and the rotor would move CW to the 45° position.

5-105. At time T3, phase A is zero and phase B is maximum positive. The resultant magnetic field causes the rotor to move to the 90° position as shown in figure 5-30D. At time T4, the amplitude is the same, but the polarity is opposite. The resultant magnetic field would place the rotor at the 135° position as shown in figure 5-30E. At time T5, phase A is maximum negative and phase B is zero. The rotor will move to the 180° position as shown in figure 5-30F. The rotor has now made one half turn with one half cycle of the applied AC. This is called the synchronous speed of the motor. The rotor follows the rotation of the rotating magnetic field set up by the stator windings. This is the basic principle of all AC induction motors. The rotor will attempt to follow the rotating magnetic field.

5-106. Two phase power is not a common power source. The most common polyphase AC power is three phase. The stator windings of a three phase motor could be connected in either a delta or wye configuration as shown in figure 5-31. In three phase power there is a 120° electrical separation between the phases. The stator field coils are wound to give a physical separation of 60° between each pair of poles as shown in figure 5-32. In actual practice the poles are not easily identified as individual pole pieces because the windings on the stator overlap. The rotor is not shown.

5-107. The primary purpose of any motor is to convert electrical energy into mechanical energy. The rotating magnetic field of the stationary windings of AC motors must be strong enough to cause mechanical motion. This mechanical motion is provided by the rotor (to which gears and other mechanical linkages are attached) which fits inside the stationary stator.

5-108. Types of AC Motors.

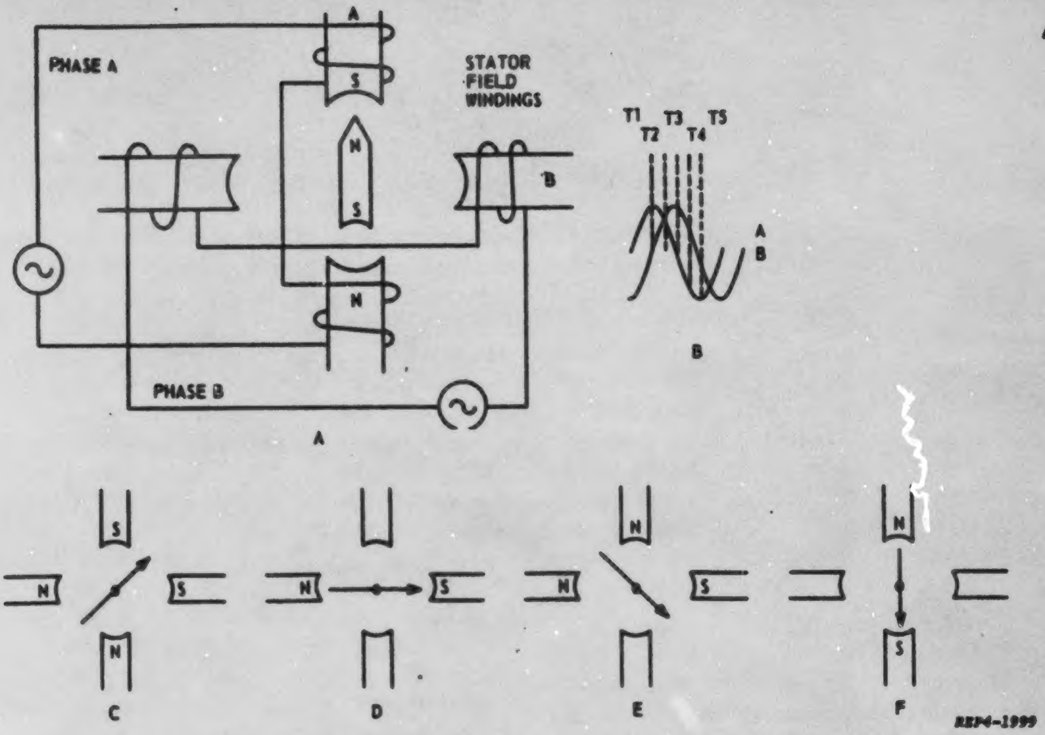


Figure 5-30. AC Motor Principle

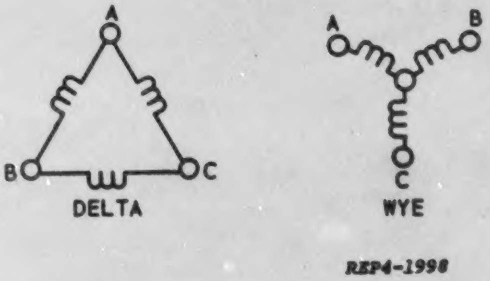


Figure 5-31. Three Phase Connections

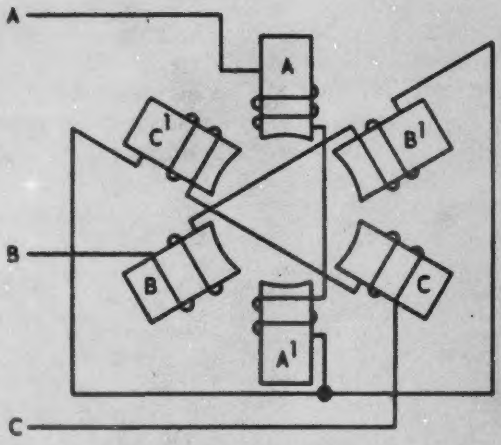


Figure 5-32. Pole Placement

5-109. Synchronous Motors. The operation shown in figure 5-30 is effectively that of a synchronous motor. The permanent magnet is replaced with an electromagnet rotor, energized by DC. Slip rings and brushes are used to make connections for the steady current through the rotating electromagnet.

5-110. As the AC magnetic field in the stator rotates, the DC field rotates to keep aligned with it. The speed of the rotating field depends on the frequency of the applied AC. The synchronous motor cannot operate at any speed except that of the rotating field. This type motor is used where it is important to maintain constant speed.

5-111. Induction Motor. In the induction motor, there are no connections to the rotor; it is a self-contained unit. The induction motor derives its name from the fact that currents are induced in the rotor by the rotating magnetic field of the stator.

5-112. The rotor of the induction motor is a laminated cylinder with slots in its surface. The windings in these slots are one of two types. The most common is called a SQUIRREL-CAGE winding. This winding consists of heavy copper bars connected together at each end by a metal ring. The other type of winding contains shorted coils of wire placed in the rotor slots. This type of rotor is called a WOUND ROTOR.

5-113. Whether wound or squirrel-cage, the basic principle of operation is the same. This motor operates on the transformer principle, with the stator acting as the primary winding and the rotor acting as the secondary winding. When an alternating current is applied to the primary of a transformer, a varying magnetic field is established, which induces a voltage into the secondary winding. The rotating magnetic field generated by the stator induces a voltage in the rotor. When voltage is induced, current flows and creates a magnetic field. Thus, we have a rotor magnetic field which interacts with the stator magnetic field to make the rotor rotate.

5-114. It is impossible for the rotor of an induction motor to turn at the same speed as the rotating magnetic field. If the speeds were the same, no relative motion would exist between the two and no induced current would result in the rotor. Without the induced current, a turning force would not be exerted on the rotor. The rotor must rotate at a speed less than that of the rotating magnetic field.

5-115. Split-Phase Motor. The split-phase motor is a single-phase induction motor. The term split-phase refers to what happens to the single-phase input voltage within the motor. In order to operate an induction motor from one phase the single-phase input is SPLIT by inserting a capacitor or resistor in series with one field coil winding.

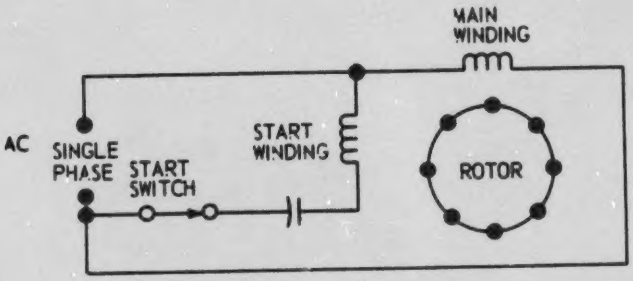


Figure 5-33. Split Phase Motor

5-116. Figure 5-33 shows one type of split-phase induction motor. It uses a combination of capacitance, inductance, and resistance to develop a rotating field. This type of induction motor is called a capacitor-start type. The stator circuit consists of two legs. One leg has the main winding, and the other leg has the start winding. The windings are mechanically spaced at right angles to each other. An electrical phase difference between the two windings is obtained by connecting a capacitor in series with the start winding. The result is a 2-phase magnetic field which starts the motor by providing a rotating magnetic field as explained for the two phase motor. When 60% of full speed is obtained, the start switch opens, and the motor runs using only the main winding.

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Technical Training

ELECTRONIC PRINCIPLES MODULAR SELF-PACED)

MODULE 11

AC COMPUTATION AND FREQUENCY SPECTRUM

1 June 1974

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ELECTRONIC PRINCIPLES

MODULE 11

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

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Supersedes KEP-GP-11, 1 November 1973. Use old stock until exhausted.

AC COMPUTATION AND FREQUENCY SPECTRUM

1. SCOPE: In this module you will study the characteristics of alternating current. Most Electronic Equipment has an AC signal as a medium to carry the intelligence through it and is an important component of its transmitting signal.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given waveforms that represent alternating current, identify their characteristics in terms of:

(1) cycle

(2) period

(3) alternation

(4) amplitude

b. Given either the effective, average, peak, or peak-to-peak sine wave voltage and formulas, compute the other values.

c. Given a pictorial representation of the frequency spectrum, identify the ranges of power, radio, audio, and microwave frequencies.

d. Given either the frequency, period, or wavelength of a sine wave and formulas, compute the other values.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK.

IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

AC COMPUTATION AND FREQUENCY SPECTRUM

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest

Adjunct Guide with Student Text

AUDIO-VISUALS

Television Lesson, Frequency Spectrum, TVK 30-204

Television Lesson, Definition and Analysis of AC, TVK 30-200

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

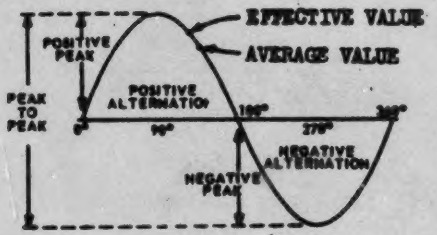
AC COMPUTATION AND FREQUENCY SPECTRUM

In previous lessons, you studied current which flows in one direction only. Now, you are ready to take up current which alternately flows in two directions.

ALTERNATING CURRENT (AC).

Alternating current is the term applied to current which periodically reverses its direction.

The sine wave is the most common AC waveform. In fact, the sine wave is so widely used that when we think of AC, we automatically think of the sine wave. Household AC is a sine wave. Let us examine an AC sine wave using the figure.



Notice that the horizontal line divides the sine wave into two equal parts -- one above the line and the other below it. The portion above the line represents the POSITIVE ALTERNATION and the portion below the line represents the NEGATIVE ALTERNATION. The sine wave continuously changes amplitude and periodically reverses direction. Notice that the wave reaches its maximum swing from zero at 90° and 270°. Each of these points is called the PEAK of the sine wave. When we speak of the PEAK AMPLITUDE of a sine wave, we mean the maximum swing, or the height of one of the alternations at its peak. These terms apply to either current or voltage and are important to remember because you will be using them throughout your electronics career.

Next, let us take the term: PEAK-to-PEAK. This term, as you can see in the figure, represents the difference in value between the positive and negative peaks of the wave. Of course, this is equal to twice the peak value: $E_{pk-pk} = 2 E_{pk}$ for a sine wave.

Another useful value for the sine wave is the EFFECTIVE value. The effective value of a sine wave is the amount which produces the same heating effect as an equal amount of DC. Since the heating effect of current is proportional to the square of the current, we can calculate the effective value by squaring the instantaneous values of all the points on the sine wave, taking the average of these values, and extracting the square root. The effective value is, thus, the root of the mean (average) square of these values. This value is known as the ROOT-MEAN-SQUARE, or rms value. When we speak of household voltage as having a value of 110 volts, we mean that it has an effective or rms value of 110 volts. Unless otherwise stated, AC voltage or current is expressed as the effective value.

DIGEST

A sine wave with a peak amplitude of 1 volt has an effective value of .707 volts. This means that a sine wave of voltage whose peak value is 1 volt will have the same heating effect as .707 volts of DC. To find the effective value of a sine wave, multiply the peak value by .707.

$$E_{eff} = .707\ E_{pk}$$

The reciprocal of .707 is 1.414. Therefore, to find the peak value of a sine wave multiply the effective by 1.414:

$$E_{pk} = 1.414\ E_{eff}$$

Another sine wave value that is important to know is the AVERAGE value. This is the average of the instantaneous values of all points in a SINGLE alternation. (The average of a complete sine wave is zero).

Refer to the figure; the AVERAGE height of a single alternation is .637 times the peak value. In other words, $E_{ave} = .637\ E_{pk}$. The relationship between the average and effective values can be determined mathematically and is shown in the following formula:

$$E_{ave} = .9\ E_{eff}$$

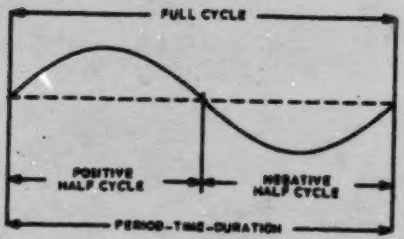
The reciprocal of .9 is 1.11. Therefore, the effective voltage is 1.11 times the average voltage:

$$E_{eff} = 1.11\ E_{ave}$$

The voltage relationships of a sine wave are summarized in the chart below.

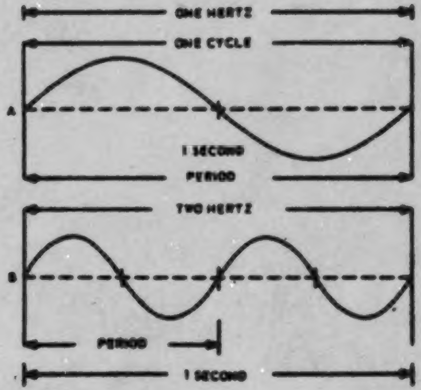
CONVERT FROM	TO GET			
	RMS EFFECTIVE	AVERAGE	PEAK	PEAK TO PEAK
RMS EFFECTIVE		0.900	1.414	2.828
AVERAGE	1.110		1.570	3.141
PEAK	0.707	0.637		2.000
PEAK TO PEAK	0.354	0.318	0.500	

Alternating current periodically reverses direction. We call two consecutive alternations, one positive and one negative, a CYCLE. We often refer to the positive and negative alternations as HALF-CYCLES. In describing the sine wave, we could say that during the positive half-cycle it rises from zero to maximum positive and then returns to zero, and that during the negative half-cycle it drops to a maximum negative value and then returns to zero.



Alternations of AC do not happen instantaneously, they take TIME. The term PERIOD is used to define the time of one cycle of alternating current. Another term having the same meaning as time and period is DURATION. The DURATION of one cycle is one-sixtieth of a second, or, "One cycle has a PERIOD of one-sixtieth of a second;" or "One-sixtieth of a second is the TIME of one cycle." All three terms have the same meaning.

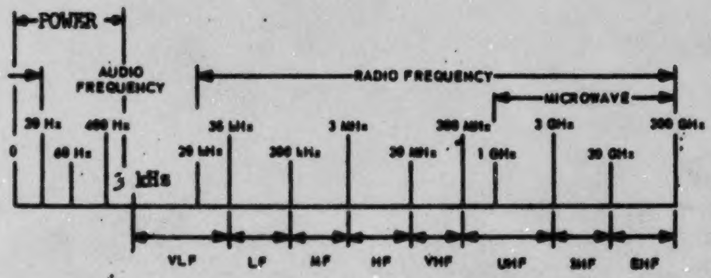
Alternating currents commonly used in aircraft have a period of one four-hundredth of a second. This means that one cycle takes one four-hundredth of a second and in one second there are four hundred complete cycles. The number of cycles in one second brings up a new term - FREQUENCY. The frequency of an AC is the number of cycles that occur in one second. This brings us to another term - HERTZ. HERTZ is a UNIT OF FREQUENCY EQUAL TO ONE CYCLE PER SECOND. Instead of saying sixty cycles per second, we will say sixty Hertz (Hz).



As you can see in the figure, there is a definite relationship between the period of an alternating current and the frequency of the current. Sine wave B has a period that is one-half the period of sine wave A, and a frequency that is twice the frequency of sine wave A. As the period for one cycle becomes shorter, the frequency increases or as the frequency increases, the period of one cycle becomes shorter.

DIGEST

Frequencies are classified as to their usage. See the following figure.



Wavelength is the distance traveled by a wave during the period of one cycle and is measured in meters. Wavelength involves two factors: speed and time. Speed is the rate of movement or, velocity. Electromagnetic waves move away from a source at a velocity of 300 million meters per second. Time is the period of one cycle and is determined by the frequency of the wave. This is expressed by the relationship:

$$t = \frac{1}{f}$$

The symbol for wavelength is the Greek letter Lambda (λ). It is equal to VELOCIY (V) times TIME (t). The formula is:

$$\lambda = Vt$$

Substituting frequency for time, the wavelength may also be expressed as:

$$\lambda = \frac{V}{f}$$

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

AC COMPUTATION AND FREQUENCY SPECTRUM

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text Volume II and read paragraphs 1-1 thru 1-11. Return to this page and answer the following questions.

1. Define the following terms as they apply to a sine wave.

a. Alternating Current ______________________________

____

b. Peak-to-Peak Amplitude ______________________________

____

c. Alternation ______________________________

____

d. Peak Amplitude ______________________________

____

e. Sine Wave ______________________________

____

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

B. Turn to Student Text Volume II and read paragraphs 1-12 thru 1-18. Return to this page and answer the following questions.

1. Find the effective values for each voltage listed below.

a. $20\ V_{pp}$ = ________ V_{eff} $(V_{eff} = .354 \times V_{pp})$

b. $90\ V_{av}$ = ________ V_{eff} $(V_{eff} = 1.11 \times V_{av})$

c. $100\ V_{p}$ = ________ V_{eff} $(V_{eff} = .707 \times V_{p})$

ANSWERS TO A

a. Alternating Current - Current which periodically reverses its direction.

b. Peak-to-Peak Amplitude - The difference value between the positive peak value and the negative peak value.

c. Alternation - Variation, either positive or negative, of a waveform from zero to maximum and back to zero.

d. Peak Amplitude - Maximum displacement from the zero position of an alternating current.

e. Sine Wave - Wave in which the amplitude varies continuously and periodically reverses direction.

If you missed ANY questions, review the material before you continue.

2. Find the average values for each voltage listed below.

a. 50 V_p = ________ V_{av} ($V_{av} = .637 \times V_p$)

b. 10 V_{eff} = ________ V_{av} ($V_{av} = .9 \times V_{eff}$)

c. 25 V_{pp} = ________ V_{av} ($V_{av} = .318 \times V_{pp}$)

3. Find the peak values for each voltage listed below.

a. 100 V_{eff} = ________ V_p ($V_p = 1.414 \times V_{eff}$)

b. 20 V_{pp} = ________ V_p ($V_p = .5 \times V_{pp}$)

c. 50 V_{av} = ________ V_p ($V_p = 1.57 \times V_{av}$)

4. Find the peak-to-peak values for each voltage listed below.

a. 20 V_{eff} = ________ V_{pp} ($V_{pp} = 2.828 \times V_{eff}$)

b. 70 V_{av} = ________ V_{pp} ($V_{pp} = 3.141 \times V_{av}$)

c. 10 V_p = ________ V_{pp} ($V_{pp} = 2 \times V_p$)

130

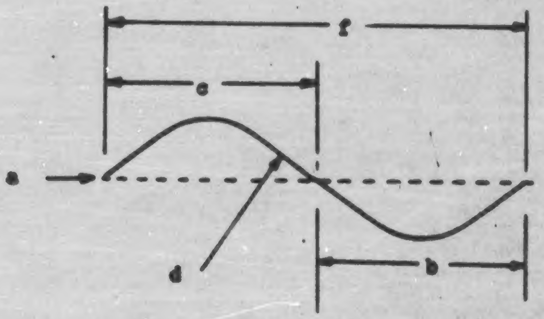
5. In the chart below supply the missing values.

V_{eff}	V_{av}	V_p	V_{pp}
70.7 V			
	90 V		
		500 V	
			25 V

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

C. Turn to Student Text Volume II and read paragraphs 1-19 thru 1-33. Return to this page and answer the following questions.

1. Match the lettered parts of the graph to their appropriate terms.



________________ (1) Sine Wave

________________ (2) Cycle

________________ (3) Positive Half Cycle

________________ (4) Period

________________ (5) Negative Half Cycle

________________ (6) Zero Reference

ADJUNCT GUIDE

ANSWERS TO B

1. a. 7.08 V_{eff}
   b. 99.9 V_{eff}
   c. 70.7 V_{eff}
2. a. 31.85 V_{av}
   b. 9 V_{av}
   c. 7.95 V_{av}
3. a. 141.4 V_p
   b. 10 V_p
   c. 78.5 V_p
4. a. 56.56 V_{pp}
   b. 219.87 V_{pp}
   c. 20 V_{pp}
5.

V_{eff}	V_{av}	V_p	V_{pp}
70.7 V	63.7 V	100 V	200 V
100 V	90 V	141.3 V	282.6V
282.8 V	254.8 V	400 V	800 V
8.85 V	7.96 V	12.5 V	25 V

If you missed ANY questions, review the material before you continue.

2. Define the following terms as they apply to a sine wave.

   a. Cycle ______________________________

   ____

   ____

b. Time ______________________________

____

c. Period ______________________________

____

d. Duration ______________________________

____

e. Frequency ______________________________

____

f. Hertz ______________________________

____

g. In-Phase ______________________________

____

h. Out of Phase ______________________________

____

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

D. Turn to Student Text Volume II and read paragraphs 1-34 thru 1-40. Return to this page and answer the following questions.

ANSWERS TO C

1. ___d___ (1)
   ___f___ (2)
   ___c___ (3)
   ___f___ (4)
   ___b___ (5)
   ___a___ (6)

2. a. Cycle - Two consecutive alternations, one positive and one negative, forms one cycle.

   b. Time - Refers to the time required for one cycle.

   c. Period - The time of one cycle.

   d. Duration - The time of one cycle.

   e. Frequency - Number of cycles that occur in one second.

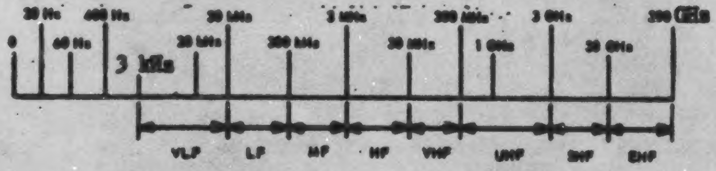
   f. Hertz - Unit of frequency equal to one cycle per second.

   g. In-Phase - When two sine waves of the same frequency pass through zero and reach their positive peaks at the same time, they are in-phase.

   h. Out-of-Phase - When two sine waves of the same frequency DO NOT pass through zero at the same time and DO NOT reach their positive peaks at the same time, they are out-of-phase.

If you missed ANY questions, review the material before you continue.

1. Given a pictorial representation of the frequency spectrum, identify the ranges of power, audio, radio, and microwave frequencies.



CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

E. Turn to Student Text Volume II and read paragraphs 1-41 thru 1-66. Return to this page and answer the following questions.

1. Compute the period of a sine wave whose frequency is 20 MHz.

   $t = \frac{1}{f} =$ __________ μs

2. Compute the frequency of a sine wave whose period is 50 μs.

   $f = \frac{1}{t} =$ __________ MHz

3. Compute the wavelength (λ) of a wave whose frequency is 3 kHz.

   $\lambda = \frac{V}{f} =$ __________ m

4. Compute the wavelength (λ) if the time of one cycle is 20 μs.

   $\lambda = t \times V =$ __________ m

5. Compute the time if the wavelength is 3 meters.

   $t = \frac{\lambda}{V} =$ __________ μs

6. Compute the frequency of a sine wave whose wavelength is .05 meters.

   $f = \frac{V}{\lambda} =$ __________ Hz

7. Given either the frequency, period, or wavelength of a sine wave and formulas, compute the other values to complete the chart below.

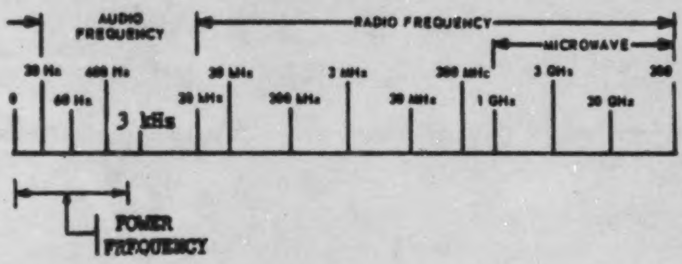
PERIOD	FREQUENCY	WAVELENGTH
.01 μs		
20 μs		
	400 Hz	
		1.8 km

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

ADJUNCT GUIDE

ANSWERS TO D

1.



If you missed ANY questions, review the material before you continue.

ANSWERS TO E

1. .05 μs

2. .02 MHz

3. 100 km

4. 6 km

5. .01 μs

6. 6 GHz

7.

PERIOD	FREQUENCY	WAVELENGTH
.01 μs	100 MHz	3 m
20 μs	50 kHz	6 km
2.5 ms	400 Hz	750 km
6 μs	166 kHz	1.8 km

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

AC COMPUTATION AND FREQUENCY SPECTRUM

Questions:

1. A sine wave of voltage ______ ______ in amplitude and ______ reverses direction.

2. A sine wave of current will reach its positive ______ value once per cycle.

3. AC makes ______ complete reversals per cycle.

4. A sine wave starting at the 0° point reaches ______ amplitude at the 90° point.

5. Match the following from the voltage waveshape shown.

   a. period ______

   b. positive half-cycle ______

   c. full-cycle ______

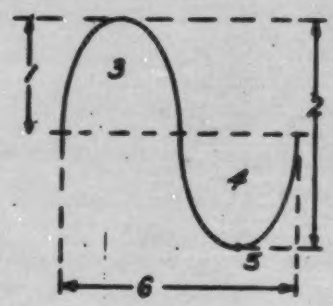
   d. positive peak amplitude ______

   e. negative peak voltage ______

   f. peak-to-peak amplitude ______

   g. negative alternation ______

   h. positive alternation ______



6. Find the peak, effective, and average voltage of each peak to peak voltage listed:

   a. 200 volts
      (1) PEAK ______
      (2) EFF ______
      (3) AVG ______

   b. 10 kilovolts
      (1) PEAK ______
      (2) EFF ______
      (3) AVG ______

7. Find the peak and average voltage of each of the effective voltages listed.

   a. 110 volts
      (1) PEAK ______
      (2) AVG ______

   b. 10 kilovolts
      (1) PEAK ______
      (2) AVG ______

MODULE SELF-CHECK

8. Find the effective voltage of each of these average values:

a. 100 volts ____________

b. 3 millivolts ____________

9. Find the number of current reversals for each of the following frequencies:

a. 60 Hertz ____________

b. 400 Hertz ____________

10. The two main characteristics of alternating current are

_____ a. constant amplitude and periodic change in direction.

_____ b. periodic amplitude and unidirectional flow.

_____ c. varying amplitude and periodic reversal of direction.

_____ d. bidirectional amplitude and periodic flow.

11. The term which represents the difference between the maximum positive and maximum negative values of an AC sine wave is called the

_____ a. effective value.

_____ b. peak-to-peak value.

_____ c. average value.

_____ d. RMS value

12. Which value of AC has the same heating capacity as DC?

_____ a. Effective.

_____ b. Peak.

_____ c. Average.

_____ d. Peak-to-peak

13. Another term that can be used to identify the effective value of AC is

_____ a. peak.

_____ b. peak-to-peak.

_____ c. average.

_____ d. RMS.

14. The term used to indicate the number of cycles of AC that occur in one second is called

______a. frequency.

______b. amplitude.

______c. RMS value.

______d. reversals.

15. If the current goes negative at the same time that the voltage producing it goes positive, the current is said to be

______a. purely resistive.

______b. in-phase with the voltage.

______c. leading the voltage by 90°.

______d. 180° out-of-phase.

16. Fill in the blank spaces under Column B with the frequencies which are included in the frequency bands listed in Column A.

A	B
DC	______________
Household Power	______________
Aircraft Power	______________
Audio Frequency	______________
Radio Frequency	______________

17. Two broad frequency classifications which make up the frequency spectrum are

______a. power and radio.

______b. radio and television.

______c. DC and AC.

______d. audio and radio.

18. The audio-frequency band includes the

______a. power frequencies 60 and 400 Hz.

______b. UHF frequencies.

______c. VHF frequencies.

______d. microwave frequencies.

MODULE SELF-CHECK

19. Which of the frequencies listed could be included in all of the following bands: radio and microwave?

_____ a. 20 kHz
_____ b. 35 kHz
_____ c. 350 MHz
_____ d. 2000 MHz

20. To be considered in the microwave category, an AC must have a frequency which is over

_____ a. 100 MHz.
_____ b. 300 MHz.
_____ c. 1000 MHz.
_____ d. 3000 MHz.

21. Find the two missing values of wavelength, frequency, or period:

	FREQUENCY	WAVELENGTH	PERIOD
a.	50 megahertz	________	________
b.	________	20,000 meters	________
c.	________	________	10 microseconds
d.	________	2 meters	________
e.	________	________	25,000 microseconds
f.	50,000 kilocycles	________	________

22. Wavelength is the measurement of

_____ a. time.
_____ b. time and distance.
_____ c. distance.
_____ d. distance and speed.

23. The wavelength of an electromagnetic wave is determined by its

_____ a. velocity and frequency.
_____ b. velocity per second.
_____ c. frequency and time.
_____ d. magnitude.

140

24. To find the frequency of an AC when you know its wave-length, you divide the

_____a. velocity by the period of one second.

_____b. wavelength by the velocity.

_____c. velocity by the wavelength.

25. The formula for finding wavelength is

_____a. $\lambda = \frac{V}{t}$

_____b. $\lambda = Vf$

_____c. $\lambda = \frac{f}{V}$

_____d. $\lambda = \frac{V}{f}$

26. Electromagnetic waves travel at approximately

_____a. 186,000 meters per second.

_____b. 186,000 miles per hour.

_____c. 300,000,000 meters per second.

_____d. 300,000,000 meters per hour.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK

1. continuously changes, periodically
2. peak
3. 2
4. maximum or peak
5. a. 6
   b. 3
   c. 6
   d. 1
   e. 5
   f. 2
   g. 4
   h. 3
6. a. (1) 100 V
   (2) 70.7 V
   (3) 63.7 V
   b. (1) 5 kV
   (2) 3535 V
   (3) 3180 V
7. a. (1) 155.5 V
   (2) 99 V
   b. (1) 14,140 V
   (2) 9 kV
8. a. 111 V
   b. 3.33 mV
9. a. 120
   b. 800
10. c
11. b
12. a
13. d
14. a
15. d
16. 0Hz
    60 Hz
    400 Hz
    20 Hz to 20 kHz
    20 kHz - 300 GHz
17. d
18. a
19. d
20. c
21. a. 6 meters .02 µs
    b. 15 kHz 66 µs
    c. 100 kHz 3,000 meters
    d. 150 MHz .0066 µs
    e. 40 Hz 7.5 x 10^6 meters
    f. 6 meters .02 µs
22. c
23. a
24. c
25. d
26. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY?

IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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KEP-PT-11

Technical Training

Electronic Principles (Modular Self-Paced)

Module 11

AC COMPUTATION AND FREQUENCY SPECTRUM

November 1975

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

ATC Keesler 6-2374

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Radar Principles Branch
Keesler Air Force Base, Mississippi

Programed Text KEP-PT-11
November 1975

Module-11

This illustrated Programmed Text is designed to aid in the study of Alternating Current and the Frequency Spectrum. Each page contains an important idea or concept to be understood before proceeding to the next. An illustration for each objective is presented to clarify what is to be learned.

At the bottom of each page, there are a few questions to bring out the main points. These are indicated by.... It is hoped that these questions also aid in understanding the subject a little better.

Q-1 or Q-2 etc..

The answers to these questions will be found on the top of a following page, indicated as ..... Short comments may follow the answers to help understand why a question may have been missed.

A-1 or A-2 etc..

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OBJECTIVES

Upon completion of this module, you should be able to satisfy the following objectives:

a. Given waveforms that represent alternating current, identify their characteristics in terms of:

   (1) cycle
   (2) period
   (3) alternation
   (4) amplitude

b. Given either the effective, average, peak, or peak-to-peak sine wave voltage and formulas, compute the other values.

c. Given a pictorial representation of the frequency spectrum, identify the ranges of power, radio, audio, and microwave frequencies.

d. Given either the frequency, period, or wavelength of a sine wave and formulas, compute the other values.

Supercedes KEP-PT-11, 1 February 1975
Previous editions may be used.

INTRODUCTION

The flow of large quantities of electrons thru a copper wire, is called electrical "current". Direct "current" is the movement of these electrons, in only one direction thru the wire. However, there are advantages to be gained, if the flow can be easily and quickly reversed.

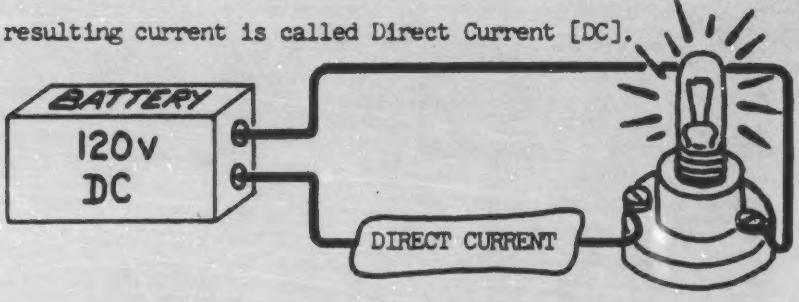
Turning the battery around, would reverse the direction of the electron flow....but this isn't enough! The electrons must be made to reverse direction, many times each second. Sometimes, many millions of times each second!

The characteristics of such a rapidly reversing electrical current, is the subject of this text. It is the study of Alternating Current.

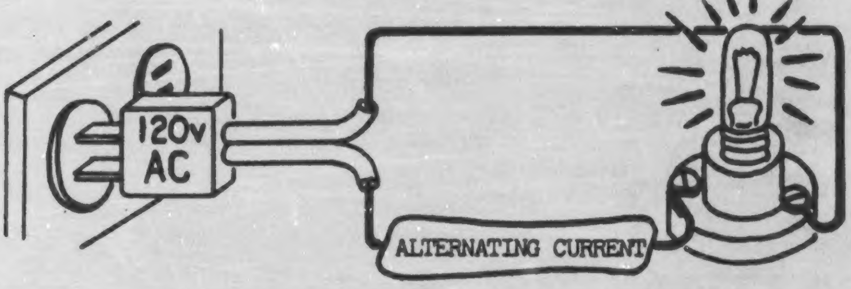
It also begins the study of an important part of Electronics, the Radio Wave. Familiar to all as Radio & Television signals, "radio waves" will now be expanded into unfamiliar areas such as Microwaves and Radar. It all begins with........

DC and AC ?

When an electric circuit obtains its power from a battery, the resulting current is called Direct Current [DC].



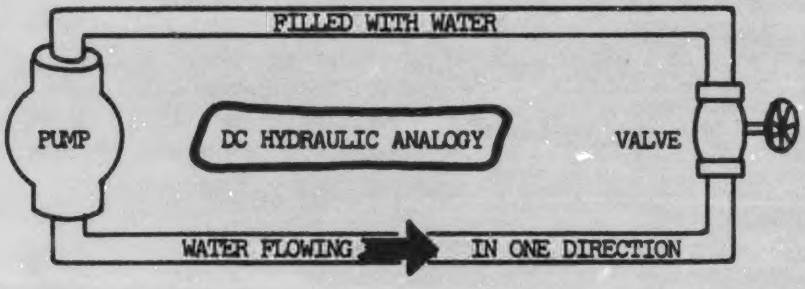
When the same circuit obtains its power from an electric outlet in a home, the electron flow is called Alternating Current [AC].



Q-1a. Battery powered circuits are called ______ Current circuits.
b. Household electric power is called ______________ Current.
c. The two letter abbreviation for Alternating Current is ___.
d. T-F Batteries provide Alternating Current. ______

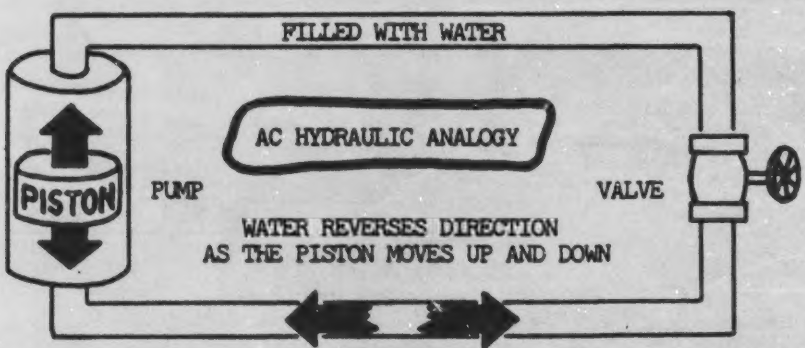
DC and AC ?

In a Direct Current [DC] circuit, the electrons always flow in one direction. The "hydraulic analogy" shows a pump (voltage), forcing water to flow (current), thru a "controlling" valve (resistance).



In an Alternating Current [AC] circuit, the electron flow "alternates"....it reverses direction.....back and forth!

The "hydraulic analogy" differs only in the type of pump used. It is a "piston-and-cylinder" arrangement. First, the piston moves up, forcing the water to flow in one direction. Then the piston moves down, and the same water is then forced to flow in the other direction. This up-and-down motion of the piston, goes on-and-on!



Q-2 a. T-F In DC Circuits, the current flows in one direction.
b. T-F In AC Circuits, the current flows in one direction.
c. T-F In AC Circuits, the current flows in two directions at the same time.

A-1 a. Direct c. AC or ac
b. Alternating d. False....only Direct Current.

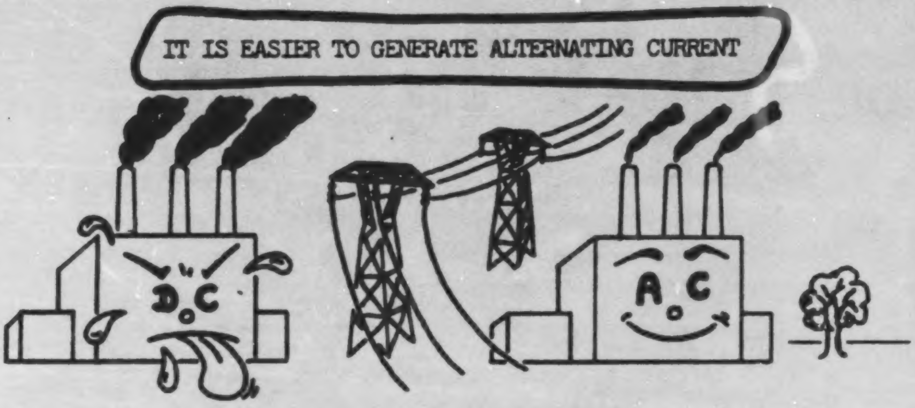
DC and AC ?

Does the direction of electron flow have any effect on the electric lamp?

The answer is......NO effect! The lamp is "lit" equally, by current flowing in either direction.

If the effects on the lamp are the same, why have Alternating Current [AC] at all? What good is it? Why not just use DC???

The questions are easy. The answers are not! There are many reasons for the use of Alternating Current. Here are some of them.


IT IS EASIER TO GENERATE ALTERNATING CURRENT
D.C
A.C

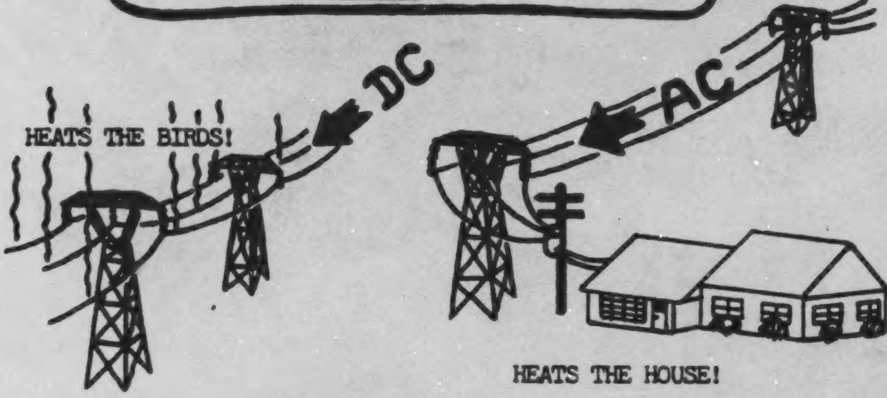
NOTE: More fully explained when electric GENERATORS are discussed.

Q-3 a. T-F The type of current (AC or DC), is important to the operation of an electric lamp.
b. T-F It is easier to generate Alternating Current than DC.

A-2 a. True
b. False
c. False....not at the same time.

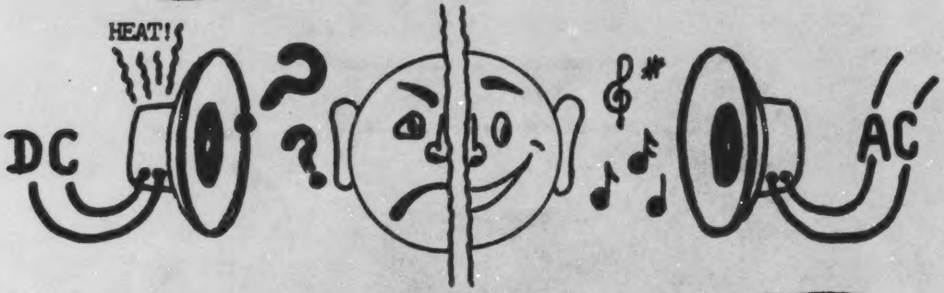
DC and AC ?

THE TRANSMISSION OF DC OVER LONG DISTANCES INVOLVES SERIOUS ENERGY LOSSES!


HEATS THE BIRDS!
DC
AC
HEATS THE HOUSE!

NOTE: More fully explained during the subject of "Transformers".

SPEAKERS OPERATE, USING ALTERNATING CURRENT



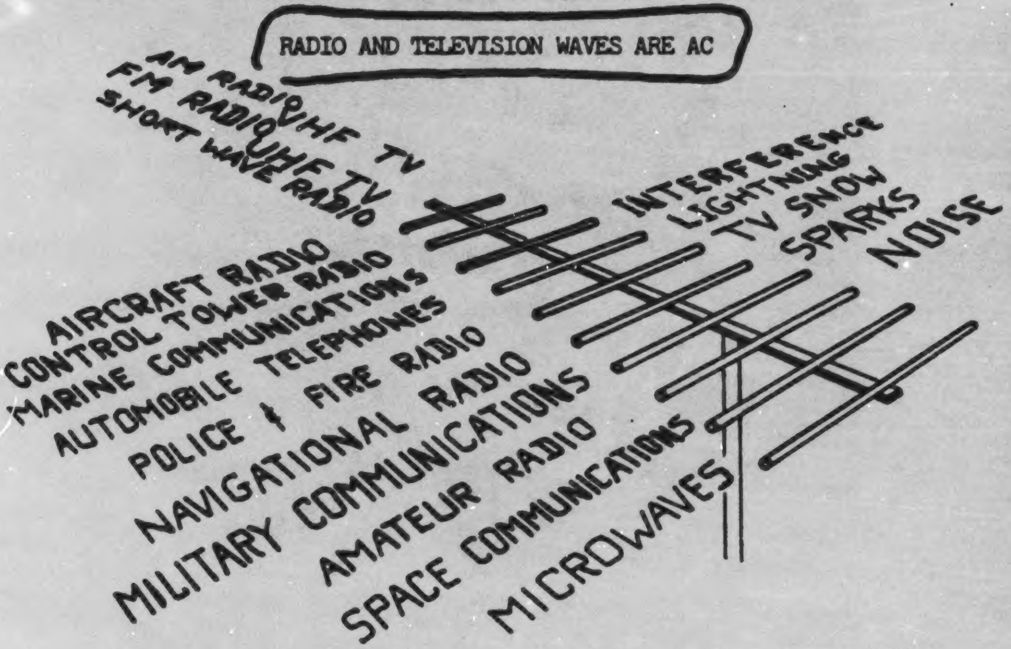
MICROPHONES AND PHONOGRAPHS PRODUCE ALTERNATING CURRENT

NOTE: More fully explained under "Microphones and Speakers".

Q-4 a. Serious energy losses occur in ________ transmission lines.
(AC or DC)

A-3 a. False....the lamp lights equally well on AC or DC.
b. True.....the machinery is less complex, and the "losses" are less. More details in "Motors & Generators".

DC and AC ?



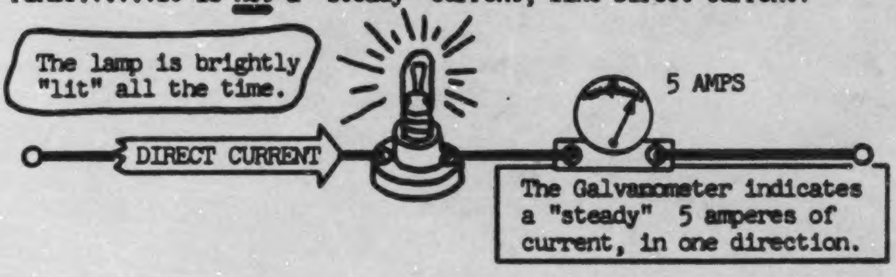
NOTE: More fully explained under "Wave Propogation".

A-4 a. DC....and the losses are "fantastic". The power companies started with DC (way back), but the need for AC soon became apparent. More details in "Motors & Generators".

DC and AC ?

The field of Electronics is deeply involved with the production and control of many types of Alternating Currents. There is much to be learned and understood about this new electric current!

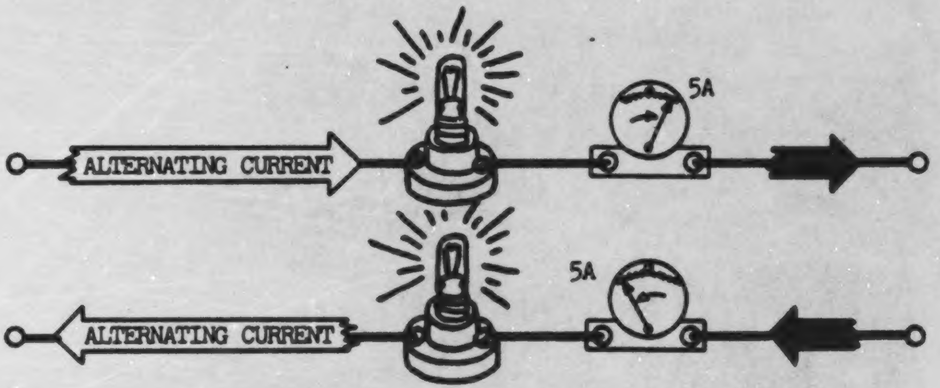
FIRST......It is not a "steady" current, like Direct Current.



The lamp is brightly "lit" all the time.

The Galvanometer indicates a "steady" 5 amperes of current, in one direction.

Alternating Current would cause the Galvanometer to swing back and forth, as the direction of current reversed.

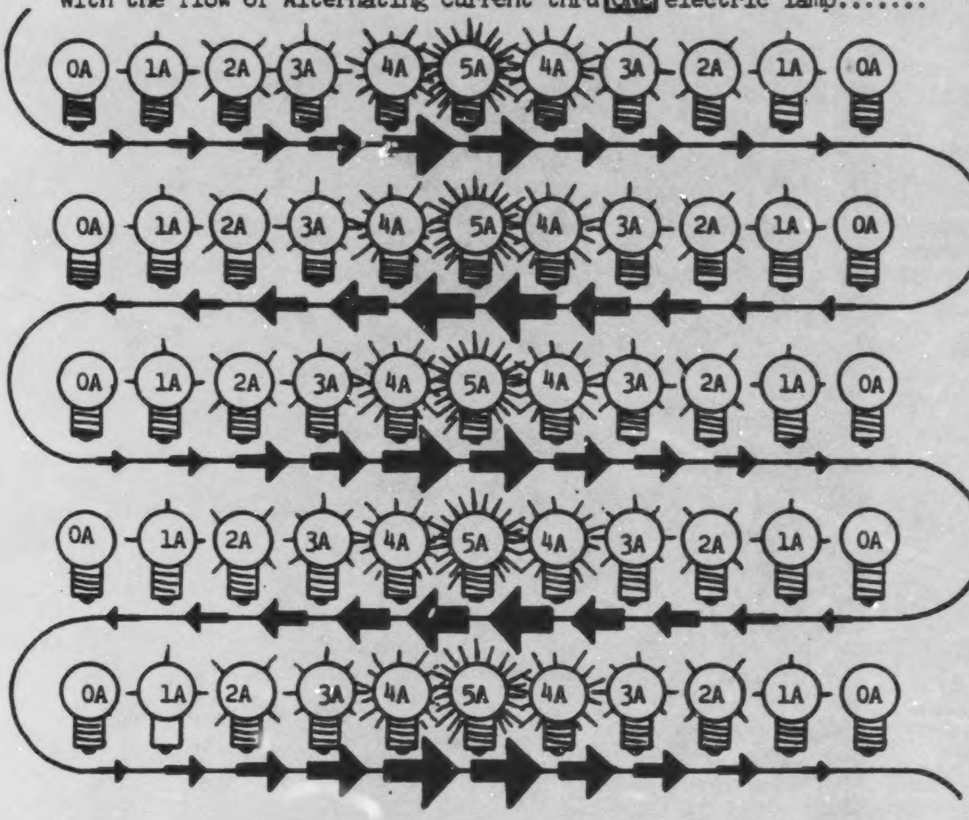


This "alternating" or back-and-forth motion of the electrical current, happens many times during ONE SECOND of time. Therefore, it is difficult (or impossible) for the "eye" to detect any difference between the AC lamp, and the DC lamp.........BUT THERE IS!!!

SLOW MOTION

An Electronic instrument called an Oscilloscope [o-sill´-o-scope] can "see" the Alternating Current in slow-motion. (The Oscilloscope will be studied and used, later in training.)

What is "seen" is interesting! First, the current DOES NOT suddenly jump from 5 amperes in one direction, to 5 amperes in the other direction. It changes gradually and smoothly. Follow along with the flow of Alternating Current thru ONE electric lamp.......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0A 1A 2A 3A 4A 5A 4A 3A 2A 1A 0A
0A 1A 2A 3A 4A 5A 4A 3A 2A 1A 0A
0A 1A 2A 3A 4A 5A 4A 3A 2A 1A 0A
0A 1A 2A 3A 4A 5A 4A 3A 2A 1A 0A

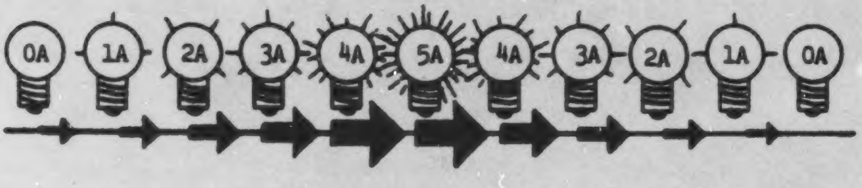
Remember! This reversing of current (and change of brightness) happens many times EACH SECOND. It is very difficult for the "eye" to see these changes. The lamp appears to be lit "steady"......like with DC.

ALTERNATIONS

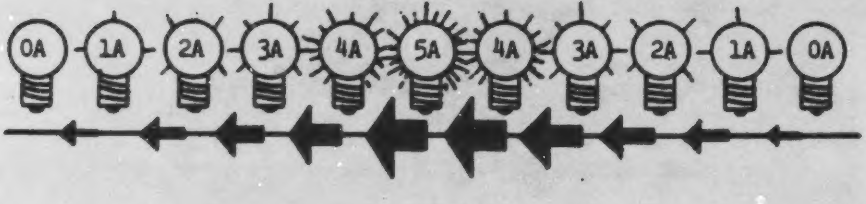
Each "rise-and-fall" of current is called an ALTERNATION.

[all-ter-naý-shun]

THIS IS A POSITIVE ALTERNATION



THIS IS A NEGATIVE ALTERNATION



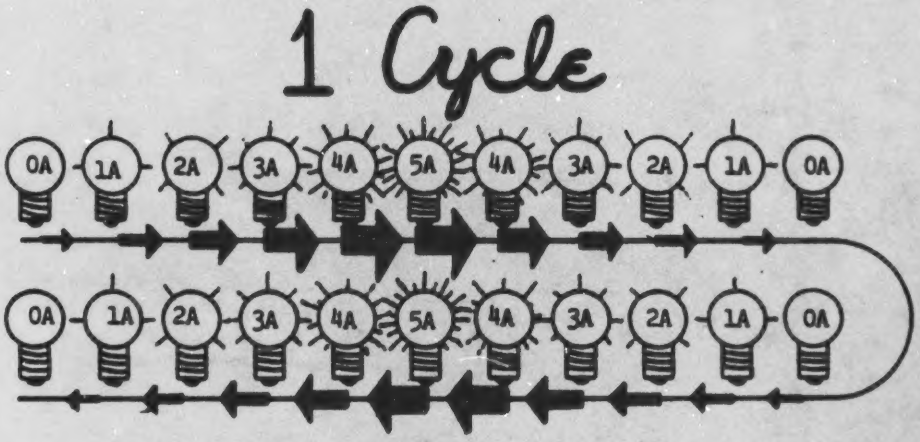
Alternating Current [AC] then, consists of a "positive" alternation, followed by a "negative" alternation, followed by another "positive" alternation, followed by another "negative" alternation, etc....

Although there are many alternations each second, each alternation takes a certain amount of time to complete. For example.....In a house, there are 120 alternations completed each second...... 60 "positive" and 60 "negative".

Q-5 a. Each "rise-and-fall" of current is called an __________.
b. Each "positive" alternation, is followed by a __________ alternation.
c. T-F Positive alternations and negative alternations occur at the same moment of time.
d. During each alternation, the electron flow is in _______ directions.

CYCLES

One "positive" alternation, followed by one "negative" alternation, is called one CYCLE.



Alternating Current [AC] then, consists of one "cycle" after another.

Although there are many "cycles" completed each second, each cycle takes a certain amount of time to complete. In a house, there are 60 "cycles" completed each second. Therefore, commercial electric power is said to be "60 cycle AC".

Of course, if there are 60 cycles completed each second, each cycle must take 1/60 of a second to complete.

Q-6 a. One "cycle" consists of ______ alternations.
b. One "positive" alternation, followed by one "negative" alternation, is called one __________.
c. T-F There are usually many "cycles" completed each second.
d. T-F Positive alternations and negative alternations occur at the same moment of time.

A-5 a. alternation
b. "negative"
c. False....not at the same moment of time. They follow along, one after another.
d. opposite.....but current in either direction will "shock" an equal amount.

FREQUENCY

In Alternating Current [AC] circuits, there are usually many "cycles" completed each second. The number of cycles completed each second, is called the "frequency" (Symbol f) of the Alternating Current [AC].

frequency (f) = The number of "cycles" of Alternating Current completed in ONE second.

EXAMPLES: Commercial electric power, has a frequency (f) of 60 cycles per second (cps or CPS)..... f = 60 cps.

On the European continent, commercial electric power has a frequency (f) of 50 cycles per second.... f = 50 cps

HERTZ

The international unit of "frequency" is the Hertz (Symbol Hz). It is equal to "one cycle per second". Also "hertz" (Symbol hz).

one hertz = one cycle per second

EXAMPLES: Commercial electric power, has a frequency (f) of 60 Hertz (Hz)...... f = 60 Hz, or f = 60 hz

On the European continent, commercial electric power has a frequency (f) of 50 Hertz (Hz)....... f = 50 Hz (or hz)

Although "hertz" has been adopted as the standard, cycles-per-second will also be used in this text, because it is "still around".

Q-7 a. The number of cycles completed each second is called the ____________ of the Alternating Current.
b. 200 cps, or 200 Hz, means there are 200 ________ completed each second.
c. The International Unit of Frequency is the __________(Hz).

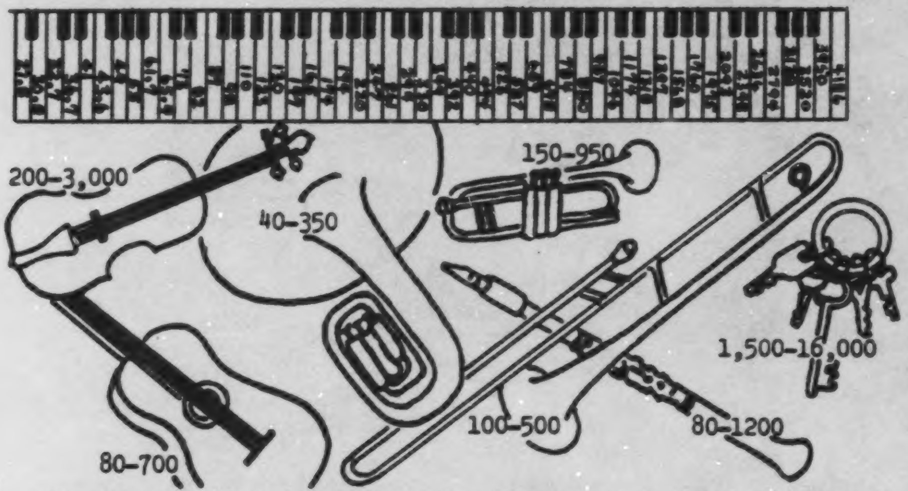
A-6
- a. two.....one positive, and one negative.
- b. Cycle.
- c. True....sometimes "millions" of cycles in one second.
- d. False...if you missed it this time, try this. Can a YO-YO go "up" and "down" at the same moment of time?

AUDIO FREQUENCIES

When Alternating Current [AC] is applied to an electric speaker, different sounds are heard. It depends upon the frequency.

At a frequency of one hertz (1 hz), the "cone" of the speaker is moving back-and-forth too slowly for any sound to be heard. If the frequency is raised to about 20 cycles per second, a very low "rumble" begins. At about 50 Hertz, it becomes a low "humming" sound. As the frequency is raised still furthur, different "tones" are heard, as pictured below.

PIANO KEYBOARD (Frequencies in CPS)



At about 20,000 Hz, the "pitch" of the sound is too high to hear, However, some animals may respond to higher frequencies, such as the "silent" dog-whistle.

AUDIO FREQUENCIES then, are described as those from a low of about 20 Hertz, to a high of about 20,000 Hertz. (Human hearing)

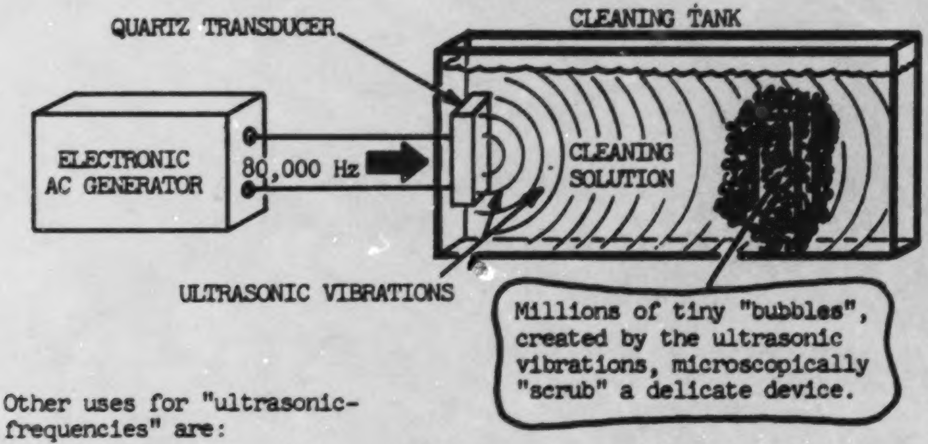
Q-8 a. If "sound" is heard when an Alternating Current is applied to a speaker, the current is said to be at an __________ frequency.

A-7
a. frequency
b. cycles
c. Hertz

ULTRASONIC FREQUENCIES

Above the range of "hearing", there are sound waves which are used for many purposes today. They are referred to as "ultrasonic frequencies".

Electric speakers cannot normally be used, because the "vibrations" are too fast. Special devices, many of them using the mineral "quartz", are used instead. These are called "ultrasonic transducers". Because of their special construction, they are capable of converting these high frequency alternating currents, into "inaudible" sound waves. One such device is the "Ultrasonic Cleaner", described below.



Millions of tiny "bubbles", created by the ultrasonic vibrations, microscopically "scrub" a delicate device.

Other uses for "ultrasonic-frequencies" are:

Ultrasonic X-Ray, without the normal "radiation" hazards.
Ultrasonic "Sonar" equipment, for underwater detection.
Ultrasonic heating, used in wood "lamination" processes.
Ultrasonic dental equipment, eliminating drill "vibrations".
Ultrasonic "intrusion alarms", for property protection.

ULTRASONIC FREQUENCIES then, range from about 20,000 Hertz, up to several million Hertz, depending upon the application.

Q-9 a. T-F Ultrasonic frequencies can be heard.
b. T-F Ultrasonic waves are electric waves.

A-8 a. "audio".....the "rising-and-falling" of the alternating current, causes the paper "cone" of the speaker to vibrate. The vibrations of the "cone" cause the air to "vibrate" also. These changes of air "pressure" are then detected by the ear "drum" and sensed as sound.

KILO-MEGA-GIGA HERTZ

Radio, Television, Microwave, and Radar equipment, involves the use of frequencies MUCH higher than "audio" or "ultrasonic". The frequencies within these types of equipment, are measured in "thousands", "millions", or "billions" of cycles per second.

It is difficult to imagine electric current reversing direction "millions" of times in one second. However, this is happening inside the Electronic circuits of a standard television set.

1,000 KILO-HERTZ 10^{+3}

One thousand cycles per second is represented as 1 Kilo cycle per second. (1 Kcps, or 1 KC, or 1 KHz, or 1 Khz, or 1 kHz)

2 KHz would equal 2,000 cycles per second.
20 KC would equal 20,000 cycles per second.

1,000,000 MEGA-HERTZ 10^{+6}

One million cycles per second is represented as 1 Mega cycle per second. (1 Mcps, or 1 MC, or 1 MHz, or 1 Mhz)

5 MHz would equal 5,000,000 cycles per second.
500 MC would equal 500,000,000 cycles per second.

1,000,000,000 GIGA-HERTZ 10^{+9}

One billion cycles per second is represented as 1 Giga cycle per second. (1 Gcps, or 1 GC, or 1 GHz, or 1 Ghz)

10 GHz would equal 10,000,000,000 cycles per second.
400 GC would equal 400,000,000,000 cycles per second.

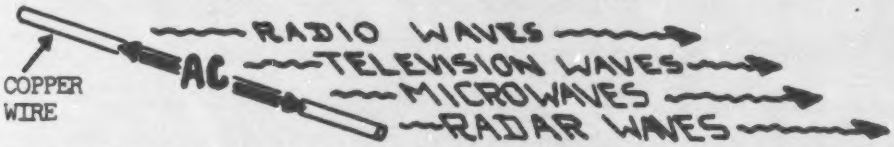
NOTE: 1 Giga Hertz formerly was identified as 1 Kilo Mega Cycle or 1 KMC. 5 GHz was 5KMC, 100 GHz was 100 KMC, etc.

A-9 a. False....the ear drum cannot "vibrate" that fast, and although the "sound" is there, it cannot be heard.
b. False....they are "sound" waves. (See above answer)

RADIO FREQUENCIES

In 1885, at the age of 28, Heinrich Hertz demonstrated a method of "transmitting" and "receiving" the waves generated by an electric spark. By 1896, at age 22, Guglielmo Marconi had improved and patented the equipment, and extended its "radio range" to about 85 miles.

One of the "keys" to Marconi's success, was his understanding of the importance of the "length" of the antenna wire. High frequency alternating currents, flowing back-and-forth on a copper wire of proper length, will produce "radio waves".



These high frequencies are referred to as Radio Frequencies. Usually shortened to "RF" or "rf", these Radio Frequencies are divided into several "bands". The equipment construction, antenna requirements, and "radiation" characteristics change, from "band" to "band", as the number of cycles per second increases.

Below ← 30KHz 300KHz 3MHz 30MHz 300MHz 3GHz 30GHz 300GHz

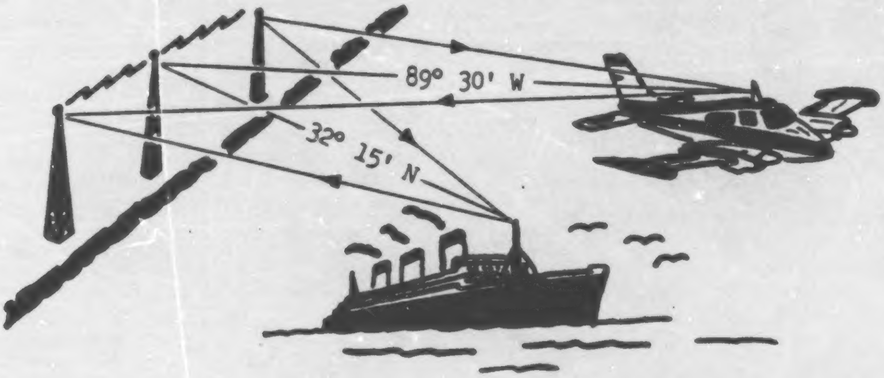
VLF BAND	LF BAND	MF BAND	HF BAND	VHF BAND	UHF BAND	SHF BAND	EHF BAND
VERY LOW FREQUENCY	LOW FREQUENCY	MEDIUM FREQUENCY	HIGH FREQUENCY	VERY HIGH FREQUENCY	ULTRA HIGH FREQUENCY	SUPER HIGH FREQUENCY	EXTREMELY HIGH FREQUENCY

VLF BAND (Below 30 KHz)

Radio waves in the Very Low Frequency Band (VLF), travel great distances over both land and water. The first uses for radio waves in this band, were for transoceanic, and long-distance maritime communications. Although some world-wide communications may still be made in this band, many of these needs are now filled by orbiting communications satellites. The antenna wires needed for this band may be several thousand meters long.

LF BAND (30 KHz to 300 KHz)

Radio waves in the Low Frequency Band (LF), also travel great distances over water and land. The main use for these frequencies is for aircraft and surface craft (ship) navigational aids. By using special electronic equipment, ships and planes can locate their positions, with fair accuracy. Many of these navigational systems now use satellite signals, for greater accuracy. The frequencies from 160KHz to 200KHz are used in the European region for broadcasting to distant rural areas. The antenna wires needed in this band may be several hundred meters long.



MF BAND (300KHz to 3MHz [3000KHz])

Radio waves in the Medium Frequency Band (MF) are used for many purposes. Perhaps the most commonly known, is AM Broadcast Radio (AM Radio). The International frequency allocation for AM Radio is from 535KHz up thru 1605KHz, with thousands of such stations operating within the United States. 1800KHz to 2000KHz (1.8MHz to 2MHz) is authorized for Loran Navigational Systems, used for position information to ships and aircraft. "Inertial" or "satellite" navigational systems are now more common than Loran. 2000KHz to 3500KHz (2MHz to 3.5MHz) is widely used by maritime and Coast Guard services, for ship-to-shore communications. The International "calling and distress" frequency of 2192KHz is also in this band. Antenna lengths in this band are measured in "tens" of meters. "S-O-S" distress calls by Morse Code are sent at 500KHz, in this band.

HF BAND (3MHz to 30MHz)

Radio waves in the High Frequency Band (HF) travel hundreds of miles. When atmospheric conditions are right, the distances may be several thousand miles. This band is probably best known as the "Short Wave" band. It contains the Overseas Broadcasting Stations (Voice of America, the BBC, etc.), Amateur Radio Service (Ham Radio), and News Wire Services (AP, UPI, etc.). Many of these radio waves carry "code", radioteletype, and facsimile (picture) signals. This band is quite crowded with radio signals. Often there is more than one station on the same frequency, creating interference with each other. Citizens Band Radio is also within this band, at about 27MHz. The National Bureau of Standards operates a special station (WWV), at 2.5MHz, 5MHz, 10MHz, 15MHz, 20MHz, and 25MHz. These radio waves carry frequency, time, and other "standards" used worldwide for many purposes. The antenna lengths in this band are measured in meters.

VHF BAND (30MHz to 300MHz)

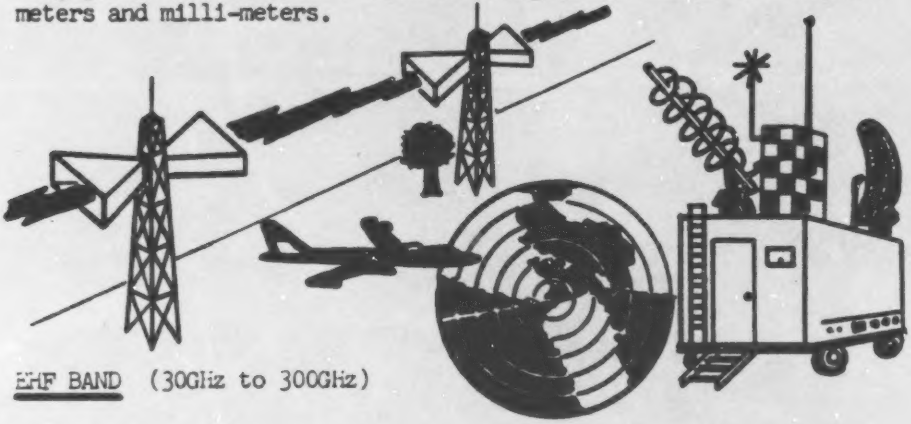
Radio waves in the Very High Frequency Band (VHF) travel relatively short distances. Generally line-of-sight, or horizon-to-horizon. Television channels 2 thru 6 (54MHz to 88MHz), FM and FM Stereo Broadcasting (88MHz thru 108MHz), and Television channels 7 thru 13 (174MHz thru 216MHz), are all within this VHF band. Commercial Aircraft (110-130MHz), Orbiting Instrumented Satellite (134-136MHz), and Space Communications (295MHz), and Amateur Radio Services (50-54MHz) use this band also. Crowding these services, are police, fire, taxi, trains, trucks, forestry, state guard, and government operated "radio-telephones", at various frequencies. Antenna lengths in this band are measured in meters and centimeters.

UHF BAND (300MHz to 3GHz [3000MHz])

Radio waves in the Ultra High Frequency Band (UHF), are also considered line-of-sight or horizon-to-horizon. Mobile Radio Telephone (police, fire, taxi, etc.), Aircraft and Control Tower, and Maritime (ship) Services, operate stations in this band. Commercial and Public UHF Television Broadcasting channels 14 thru 83 (470MHz thru 890MHz) are also transmitted. Above this, begins the Radar and Special Services frequencies. Early Warning Radars, Ground Controlled Approach (GCA) Radars, and Maritime (ship) Radars, are assigned frequencies here (900MHz to 2400MHz [2.4GHz]). Amateur Radio, Industrial, and Medical Services also are provided frequencies (2400MHz to 2500MHz [2.4GHz to 2.5GHz]). Although the "reflectors" are sometimes quite large, the actual "antennas" used are measured in centimeters. It should also be noted that radio frequencies above 1000MHz (1GHz) are additionally assigned the name "Microwaves". Microwave cooking ovens (2400MHz) operate with frequencies similar to Radars.

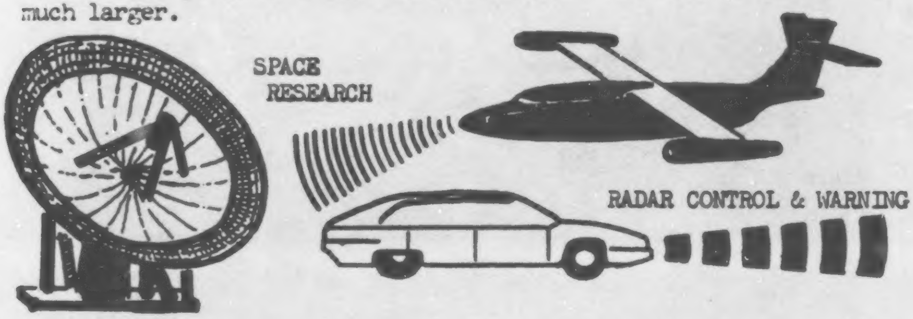
SHF BAND (3GHz to 30GHz)

Radio waves in the Super High Frequency Band (SHF), travel "line-of-sight" or "horizon-to-horizon". These frequencies are mainly used by Radar and Microwave systems. Weapons Control, Gun-laying, and Missile Control Radars operate in this band. Aircraft Navigation and Bombardment Radars, and Shipboard Fire Control Radars use radio waves at these frequencies, due to the reduction in size and weight of the antenna systems. Television and Communications signals are transported along "microwave" beams between tall towers, using SHF frequencies. Large areas of the continents are spanned by these microwave relay towers. The "reflectors" may be somewhat large, however the actual "antenna" lengths are measured in centimeters and milli-meters.



EHF BAND (30GHz to 300GHz)

Radio waves in the Extremely High Frequency Band (EHF) are considered line-of-sight. Mostly "experimental" in nature, they are widely affected by atmospheric moisture. Due to the very small antenna sizes required, very narrow beams of radio energy can be produced for varied purposes. Space communications would appear a likely candidate to utilize such narrow beams. Frequency assignments to Amateur Radio and Industrial Services may also furthur develop commercial uses for this band. High "resolution" Radar systems can produce clear electronic pictures with the narrow beams of energy. Antenna sizes are measured in milli-meters. The "reflectors", "horns", and "lenses" used to form the beams are much larger.



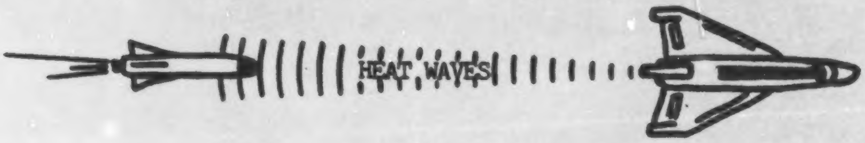
HIGHER FREQUENCIES ???

Above "radio frequencies" are energy bands familiar to many. (The frequency relationship only, will be considered.)

INFRA-RED (heat) WAVES

750GHz to 375,000GHz

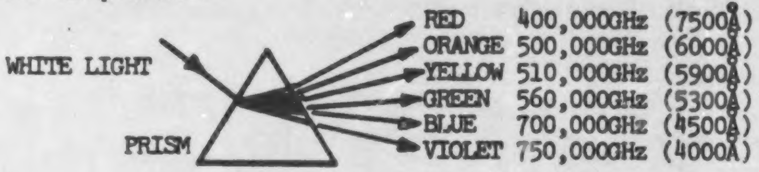
Satellite pictures are commonly made of the earths surface, using the Infra-red Waves generated by heat. Infra-red techniques are also employed in "heat seeking" missiles.



VISIBLE LIGHT WAVES

375,000GHz to 750,000GHz

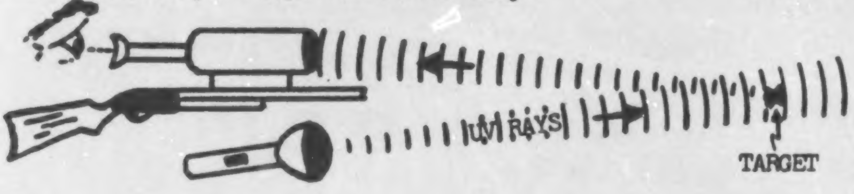
Not much needs to be said about "visible" light, if the words on this page can be seen. The different "colors" of light, have different frequencies.



ULTRA-VIOLET (Black-light) WAVES

750,000GHz to 25,000,000GHz

Satellite pictures are also made using ultra-violet waves, many of them photographs of the sun, stars, and galaxies. After a target has been illuminated with unseen ultra-violet, a sharpshooter using a "sniper-scope" can do the rest. The ultra-violet waves are made visible in the "sniper-scope" electronically.

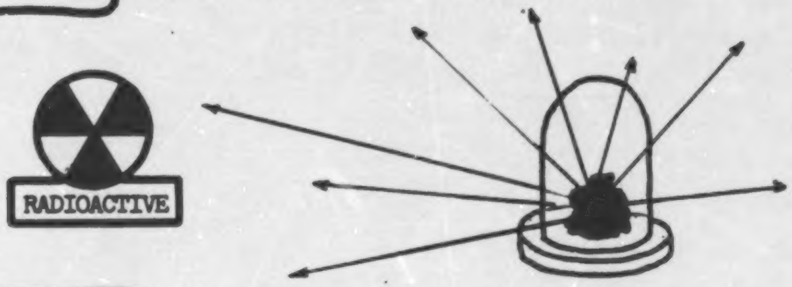


HIGHER FREQUENCIES ???

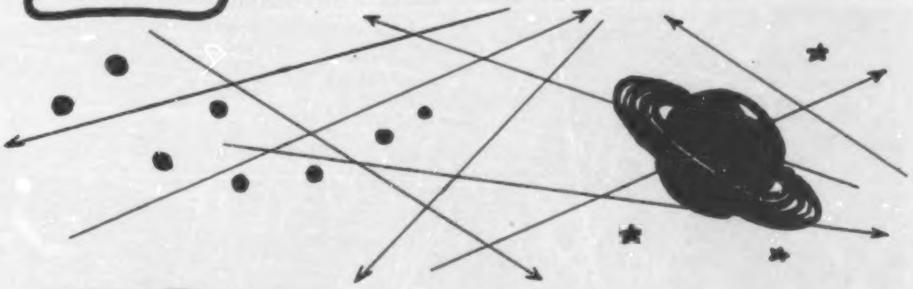
Higher in frequency than Ultra-Violet waves are:

X-RAYS 3,000,000GHz to 50,000,000,000GHz

GAMMA RAYS 1,500,000,000GHz to 300,000,000,000GHz



COSMIC RAYS 50,000,000,000GHz to 30,000,000,000,000GHz



?????? 30,000,000,000,000 GHz to ????????

THE FREQUENCY SPECTRUM

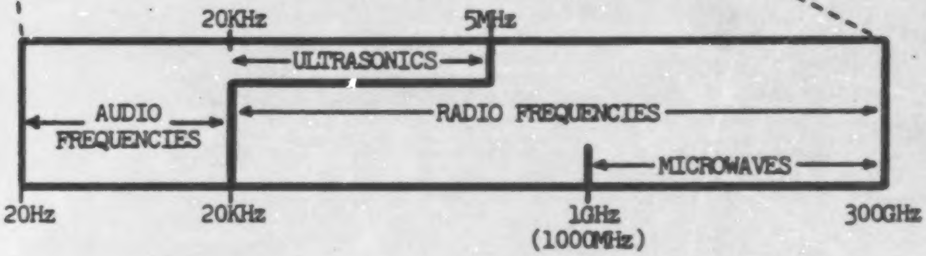
A listing, of all the various frequency "types", is called the Frequency Spectrum [specḱ-trum]. It begins with the low "audio" frequencies, and ends with the highest "cosmic rays".

THE FREQUENCY SPECTRUM

AUDIO	ULTRA SONIC	RADIO	INFRA RED	VISIBLE LIGHT	ULTRA VIOLET	X-RAYS	GAMMA RAYS	COSMIC RAYS

LOWEST FREQUENCIES → HIGHEST FREQUENCIES

In the Communications-Electronics fields, only the first part of the total Frequency Spectrum is of importance. This portion therefore will be expanded, with the important frequency limits listed.



POWER FREQUENCIES

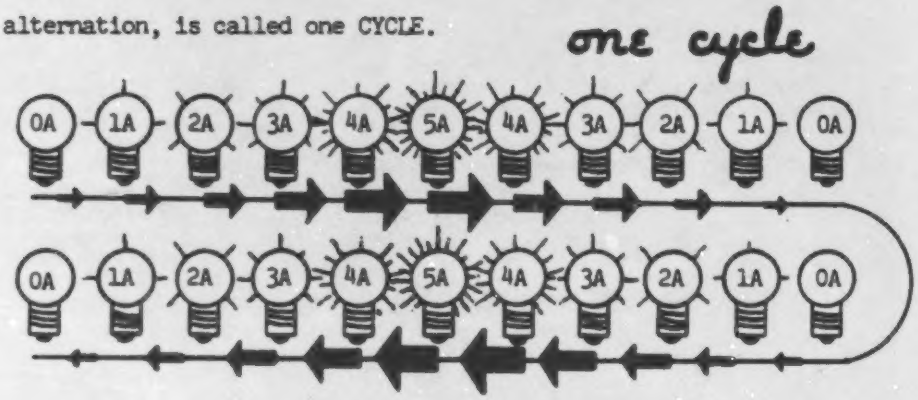
Commercial electric power in the United States, is supplied at a frequency of 60 Hertz. On the European continent, 50 Hertz is the electric power frequency. Aircraft and Surface-craft (ships), have electric power generated by on-board "alternators" at 400 Hertz. 50Hz, 60Hz and 400Hz, are known as "Power Frequencies".

NOTE: The "power frequencies" are all within the Audio Frequency portion of the Frequency Spectrum.

Q-10 a. From 20Hz to 20KHz, are called __________ frequencies.
b. From 20KHz to 300GHz, are called __________ frequencies.
c. "Microwaves" begin at ________ Hertz.

PERIOD

The completion of one "positive" alternation, and one "negative" alternation, is called one CYCLE.



It takes a certain amount of time for the alternating current to complete each cycle. The time it takes to complete any ONE cycle of Alternating Current (AC), is called the "period". The symbol used for the word "period" is "t", representing time.

period (t) = The amount of time it takes to complete any ONE cycle of Alternating Current.

If the frequency is 1 cycle per second, there is only 1 cycle completed each second.....therefore the "period" of each cycle would be 1 second (1 sec).

$f = 1\,\text{Hz} \quad t = 1\,\text{sec}$

If the frequency (f) is 2 cycles per second (2 cps), there are 2 cycles completed each second....therefore the "period" of either cycle would be 1/2 second (.5 sec).

$f = 2\,\text{Hz} \quad t = \frac{1}{2}\,\text{sec}$

If the frequency (f) equals 4 Hertz, there are 4 cycles completed each second.....therefore the period (t) of each cycle would be 1/4 second (.25 sec).

$f = 4\,\text{Hz} \quad t = \frac{1}{4}\,\text{sec}$

Q-11 a. The time it takes to complete one cycle, is called the ___.
b. If the frequency increases, the "period" ___________.
(inc or dec)

A-10 a. Audio....from around 20Hz to around 20KHz.
b. Radio....there is realy no lower limit, as the VLF Band is defined as anything below 30KHz. But it seems sensible to begin "radio" where "audio" leaves off.......OK???
c. 1GHz...1,000MHz.....1,000,000,000Hz....1 Billion Hertz!

CALCULATING PERIOD (t)

If the frequency (f) of the Alternating Current is known, the period (t) of any ONE of the cycles can be determined.

Equation $\boxed{\text{PERIOD} = \dfrac{\text{ONE}}{\text{FREQUENCY}}}$ $t = \dfrac{1}{f}$

EXAMPLE: Calculate the period (t), if the frequency (f) = 200 Hz.

$$\text{PERIOD} = \frac{\text{ONE}}{\text{FREQUENCY}} \qquad t = \frac{1}{f} = \frac{1}{200} = .005 \text{ sec}$$

EXAMPLE: The frequency = 25 Hz. Calculate the period (t).

$$\text{PERIOD} = \frac{\text{ONE}}{\text{FREQUENCY}} \qquad t = \frac{1}{f} = \frac{1}{25} = .04 \text{ sec}$$

If the frequency (f) is given in Hertz (Hz), the calculation for period (t) comes out in seconds (sec).

If the frequency (f) is given in Kilo-Hertz (KHz), the calculation for period (t) comes out in milli-seconds (mS).

If the frequency (f) is given in Mega-Hertz (MHz), the calculation for period (t) comes out in micro-seconds (µS).

If the frequency (f) is given in Giga-Hertz (GHz), the calculation for period (t) comes out in nano-seconds (nS).

EXAMPLE: Frequency (f) = 200Hz,.....Period (t) = .005 sec
Frequency (f) = 200KHz.....Period (t) = .005 mS
Frequency (f) = 200MHz.....Period (t) = .005 µS
Frequency (f) = 200GHz.....Period (t) = .005 nS

Q-12 a. What is the period of a "power frequency" of 50Hz? _____
b. What is the period of an "audio frequency" of 250Hz? _____
c. What is the period of a "radio frequency" of 100KHz? _____
d. What is the period of a "radio frequency" of 20MHz? _____
e. A "microwave frequency" of 5GHz, has a period of _____.
f. T-F As frequency increases, the period decreases.

A-11 a. Period....symbol (t)...for "time".
b. decreases.....if there are more cycles completed in a second (inc frequency), then it must take less time to complete each cycle.(dec period)

CALCULATING FREQUENCY (f)

If the time to complete ONE cycle is known, the number of cycles completed in ONE second can be determined. That is to say, if the period (t) of a cycle is known, the frequency (f) of the Alternating Current can be calculated.

Equation $\boxed{\text{FREQUENCY} = \frac{\text{ONE}}{\text{PERIOD}}}$ $f = \frac{1}{t}$

EXAMPLE: Calculate the frequency (f), if the period (t) = .005 sec.

$$\text{FREQUENCY} = \frac{\text{ONE}}{\text{PERIOD}} \qquad f = \frac{1}{t} = \frac{1}{.005} = 200 \text{ Hertz}$$

EXAMPLE: The period (t) = .04 sec. Calculate the frequency (f).

$$\text{FREQUENCY} = \frac{\text{ONE}}{\text{PERIOD}} \qquad f = \frac{1}{t} = \frac{1}{.04} = 25 \text{ Hz}$$

If the period (t) is given in seconds (sec), the calculation for frequency (f) comes out in Hertz (Hz).

If the period (t) is given in milli-seconds (mS), the calculation for frequency (f) comes out in Kilo-Hertz (KHz).

If the period (t) is given in micro-seconds (µS), the calculation for frequency (f) comes out in Mega-Hertz (MHz).

If the period (t) is given in nano-seconds (nS), the calculation for frequency (f) comes out in Giga-Hertz (GHz).

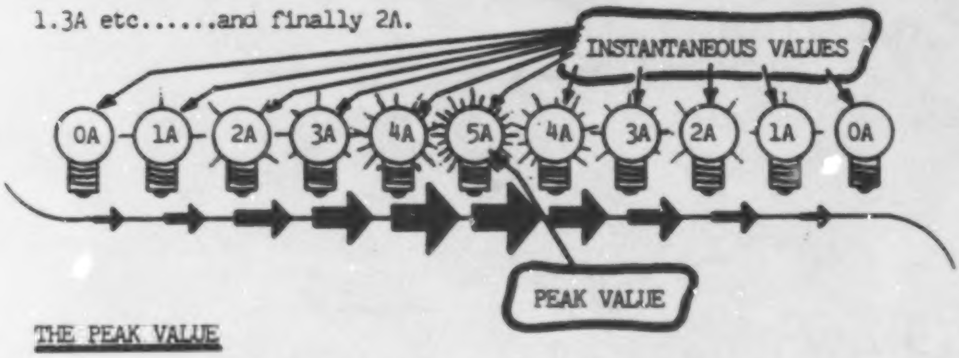
EXAMPLE: Period (t) = .04 sec.....Frequency (f) = 25 Hz
Period (t) = .04 mS .....Frequency (f) = 25 KHz
Period (t) = .04 µS .....Frequency (f) = 25 MHz
Period (t) = .04 nS .....Frequency (f) = 25 GHz

Q-13 a. Period = .002 seconds. Frequency = ___________.
b. Period = 5 milli seconds. Frequency = ____________.
c. Period = 10 micro seconds. Frequency = ____________.
d. Period = 2 nano seconds. Frequency = ______________.

A-12 a. .02 sec (20 milli sec)
b. .004 sec (4 milli sec)
c. .01mS (10 micro sec)
d. .05uS (50 nano sec)
e. .2nS (200 pico sec)
f. True....more cycles means less time for each cycle.

INSTANTANEOUS AND PEAK VALUES

In the following "positive" alternation, 0A, 1A, 2A, 3A, etc., are called the "Instantaneous" values. They represent the amount of current flowing, at various "instants" of time. Although there are only eleven "Instantaneous" values shown, there are actually an infinite number of them. For example: Between 0A and 1A there is .001A, .002A, .003A etc........ .01A, .02A, .03A etc.......... .1A, .2A, .3A, etc....and finally 1A. Between 1A and 2A there is 1.001A, 1.002A, 1.003A etc.......1.01A, 1.02A, 1.03A etc........1.1A, 1.2A, 1.3A etc......and finally 2A.



THE PEAK VALUE

There may be an infinite number of "instantaneous" values, but there is only one "peak" value reached during each alternation. This would of course be the maximum amount of electron flow. In the alternation shown, 5 amperes would be the "peak" value. The same "peak" value will be reached during each alternation. Both "positive" and "negative" alternations will have the same "peak" value.

Q-14 a. The value of current at any instant of time, is called the ____________________ value.
b. The maximum amount of current reached during each alternation, is called the _________ value.

A-13
a. 500Hz (500CPS or .5KHz or .5KC)
b. .2KHz (200Hz or .2KC)
c. .1MHz (100KHz or 100KC or 100,000 Hertz)
d. .5GHz (500MHz or 500MC or 500,000,000 Hertz)

AVERAGE VALUE

Add all the "instantaneous" values of an alternation together. Divide this "sum", by the number of values used, and the answer is called the "Average" value. (This must be done using high-level math, as there are an infinite number of "instantaneous" values.)

However, the **"Average"** value of any alternation can be easily determined by multiplying .637 times whatever the **"peak"** value equals.

Equation $\boxed{\text{AVERAGE} = .637 \cdot \text{PEAK}}$

EXAMPLE: The "peak" value = 5 amperes. Calculate the "average" value.

AVERAGE = .637 · PEAK .637 · 5A = 3.185 amperes

If the "average" value is known, the "peak" value can be determined.

Equation $\boxed{\text{PEAK} = 1.57 \cdot \text{AVERAGE}}$

EXAMPLE: The "average" value = 3.185 amperes. The "peak" value = ?

PEAK = 1.57 · AVERAGE 1.57 · 3.185 = 5.00045 amperes

NOTE: The small "error" here is due to .637 being "rounded-off".

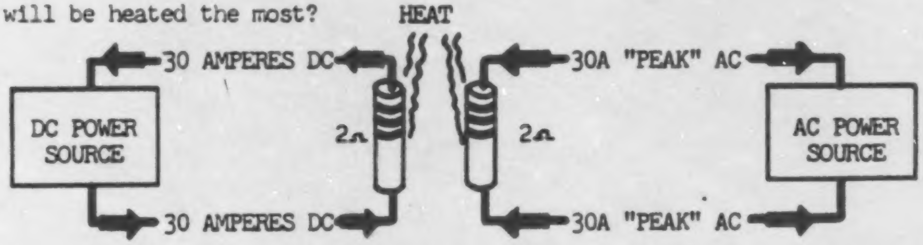
Q-15
a. A 25" Color TV uses a peak current of 4 amperes. Calculate the "average" value of current used by the set. ________.
b. The average current of a 6 transistor AM Radio is 6mA. Calculate the "peak" value of current flow used. ________.
c. An air-conditioner uses a peak current of 20 amperes. Calculate the "average" value of the current used. ________.
d. A 100 watt light bulb uses an "average" current of 800mA. Calculate the "peak" value used by the bulb. ________.
e. An electric toaster uses a "peak" current of 8 amperes. What is the "average" current used by the toaster? ________
f. Soldering-iron...Peak current 2 amps.....Average = ________.

A-14 a. "instantaneous" value.
b. "peak" value.....the "peak" value reached during each alternation is the same. For example: If the positive "peak" is 15 amperes, the negative "peak" will also be 15 amperes.

SPEAKING ABOUT HEAT....

When electrical current flows thru a resistor, heat is generated within the resistor......power dissipation.

Question? In the following DC and AC circuits, which resistor will be heated the most?



The answer? The resistor in the DC circuit will be the hottest! Why? The current flow in the DC circuit is a "steady" 30 amperes. The resistor is heated "30 amperes worth" all the time.

In the AC circuit, the resistor is heated "30 amperes worth" only at the moments of "peak" current. The rest of the "instantaneous" values are less than 30 amperes. There are times when the resistor is not being heated at all! These would be 0A....between alternations.

In order for the resistor in the AC circuit to be heated the same, the current must reach a "peak" of higher than 30 amperes.

Equation AC PEAK [For equal heat] = 1.414 · DC

EXAMPLE: DC current = 30 amperes. AC "peak" value [equal heat] = ?

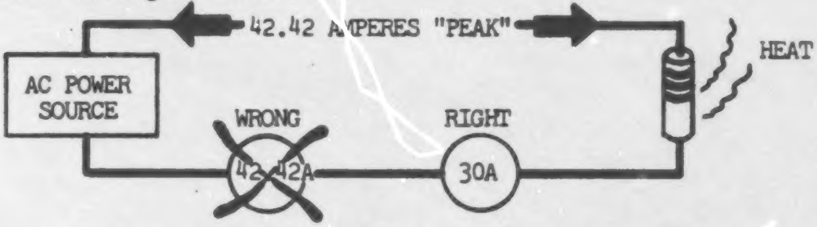
AC PEAK [equal heat] = 1.414 · DC 1.414 · 30A = 42.42A PEAK

Q-16 a. A "camper" van has a hot-plate using 6 amperes of DC current from the battery. What "peak" value of AC current will produce the same amount of heat? ________________.
b. Yes-No Will 7 amperes of AC produce the same amount of heat as 5 amperes of DC? (That's 7 amperes "peak".)

A-15 a. 2.548A AVG
b. 9.42mA PK
c. 12.74A AVG
d. 1,256mA PK or 1.256A PK
e. 5.096A AVG
f. 1.274A AVG

EFFECTIVE VALUE

AC ammeters do NOT indicate the "peak" value of the Alternating Current flowing in a circuit!



The "30 ampere" reading on the meter, indicates that the Alternating Current which is flowing, has the same "heating effect" as 30 amperes of Direct Current. The Alternating Current may have a "peak" value of 42.42 amperes, BUT.......the "heating effect" is the same as only 30 amperes of Direct Current.

The "peak" value of Alternating Current, is always higher than its "heating effect" value. This "heating effect" value is called the EFFECTIVE VALUE of Alternating Current.

Effective Value

That amount of Alternating Current, which will produce the same "heating effect", as an equal amount of DC.

AC voltmeters and ammeters are calibrated to indicate this "effective" value, rather than the "peak" value. This is an important point, and it must be kept in mind! The "effective" value (measured by AC meters), is always LOWER than the "peak" value.

Q-17 a. T-F AC meters "read" the peak value.
b. T-F AC meters "read" the average value.
c. T-F AC meters "read" the effective value.
d. T-F The "peak" value is higher than the "effective" value.
e. T-F The "effective" value is lower than the "peak" value.

A-16 a. 8.484A PK....but don't get the wrong idea. You couldn't plug the camper hot-plate into a house wall outlet. The camper battery is probably 12V, and the house 117V!
b. No...but it's pretty close (7.07A PK same as 5A DC)

CALCULATING THE EFFECTIVE VALUE

The "Effective" or "heating effect" value of an Alternating Current, is always LOWER than the "peak" value. If the "peak" value is known, the "effective" value can be determined.

Equation

EFFECTIVE = .707 · PEAK

EXAMPLE: "Peak" current equals 20 amperes. Calculate the "effective".

EFFECTIVE = .707 · PEAK .707 · 20A = 14.14 amperes

If the "effective" value is known, the "peak" value can be calculated.

Equation

PEAK = 1.414 · EFFECTIVE

EXAMPLE: "Effective" current = 2 amperes. Calculate the "peak".

PEAK = 1.414 · EFFECTIVE 1.414 · 2A = 2.828 amperes "peak".

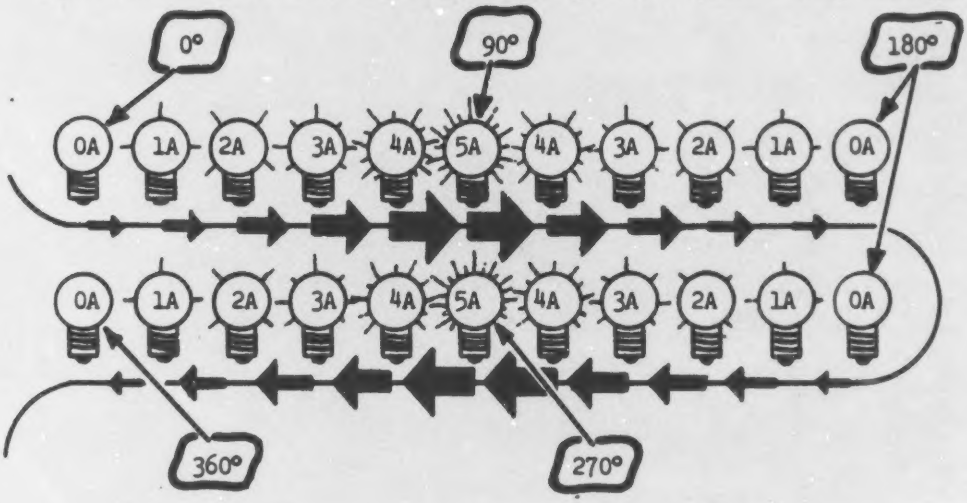
The "effective" value is sometimes called the "RMS" value. This stands for "Root Mean Square". It is a mathematical process, and will not be furthur discussed. It is the same as "effective".

Q-18 a. Which value of alternating current has the same heating effect as an equal amount of direct current? ______ value.
b. The "effective" value is also called the _ _ _ value.
c. An electric iron uses a "peak" value of 8 amperes. What is the "effective" value? ____________
d. A 60 watt light bulb operates on 500mA "effective" current. Calculate the "peak" current flowing thru the bulb. ______
e. A small "pencil" type soldering iron has a "peak" current of 2 amperes. What is the RMS current thru it? _________
f. T-F The RMS value is higher than the "effective" value.

A-17 a. False
b. False
c. True....finally got to it!
d. True
e. True....but that's saying (d) backwards)

DEGREE REPRESENTATION

One cycle of Alternating Current can be produced by, rotating a piece of copper wire, in a 360° circle, thru a magnetic field. (This will be furthur discussed in "Electric Generators".) Therefore, each cycle is marked-off in degrees, beginning with 0°, and ending with 360°.



Each cycle begins at 0°, and ends at 360°. Current reverses at the 180° point and begins each "negative" alternation. 90° is the point of "peak" current during each "positive" alternation. 270° is the point of "peak" current during each "negative" alternation.

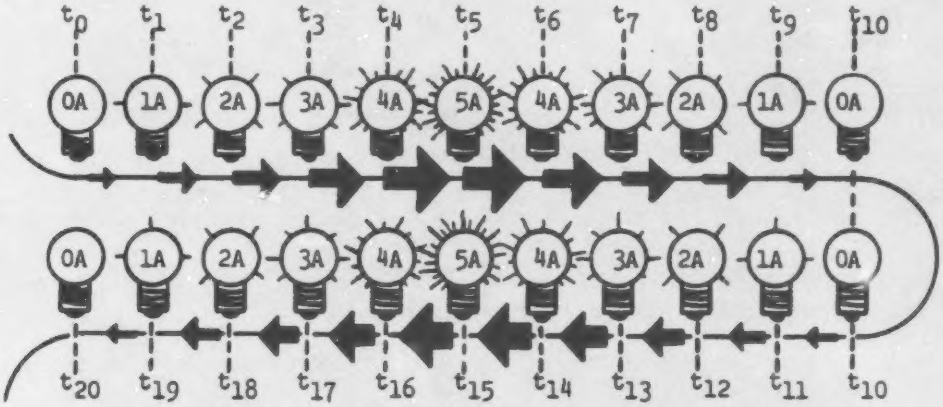
Each "instantaneous" value of current in a cycle, can be identified by using degrees. For example (using the above figure)..... What would be the "instantaneous" value of current at 85°? Answer... Somewhere between 4 and 5 amperes. The "degree representation" of a cycle will be furthur studied in this text under "Phase Difference".

Q-19 a. Each cycle contains how many degrees? ________
b. Each alternation contains how many degrees? __________
c. "Peak" currents flow at ____ and ____ degrees.

A-18
a. The "effective" value.
b. RMS or rms
c. 5.656A EFF
d. 707mA PK or about .7 amperes PK
e. 1.414A RMS or 1.414A EFF
f. False...it is the "effective"!

TIME REPRESENTATION

t_0, t_1, t_2, t_3 etc., are "time indicators". They are often placed at equally spaced points on a cycle. The distance between each "time indicator", represents a particular amount of time, such as 1 milli-second. The distance between each mark remains the same, because each milli-second is as long as any other milli-second.



If the time between each mark equals 1 milli-second, the "period" of this cycle must be 20 milli-seconds. Using the equation $f = \frac{1}{t}$, this must be one cycle of .05KHz (50Hz) alternating current.

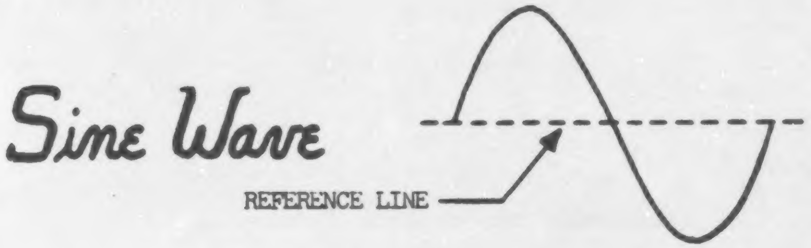
All of the points in this cycle can be identified by their "time indicators". Examples: The cycle begins at t_0, and ends at t_{20}. t_5 is when the "peak" current is reached during the "positive" alternation. t_{15} is the "negative" peak. t_{10} is the moment when the current reverses, between alternations. Between t_7 and t_8, the current is decreasing from 3 amperes to 2 amperes....etc....etc.

Q-20 Use the drawing above, to answer the following.
a. The positive alternation "peak", occurs at ______ (t_1, t_2, etc.)
b. Between t_{12} and t_{13}, the current is ________ (inc or dec).
c. The "negative" alternation begins at______ ("t" indicator)

A-19
- a. 360 degrees
- b. 180 degrees
- c. 90° and 270°

SINE WAVE REPRESENTATION

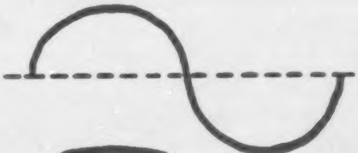
Usually, Alternating Current is represented as a "sine wave". This "sine wave" is the picture seen, when alternating current is viewed on an Oscilloscope (something like a 5" TV set).



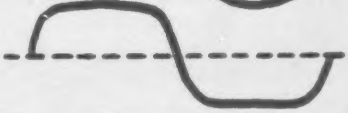
The dotted-line thru the middle of the sine wave, is called the "reference line". The sine wave goes an equal amount, above-and-below the "reference line". The points where the sine wave touches or crosses the "reference line", are equally spaced.

It should also be noticed, that the sine wave has a particular "shape".

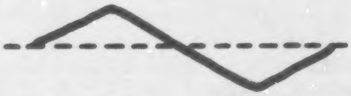
It is NOT "rounded".



It is NOT "flattened".



It is NOT "triangular".



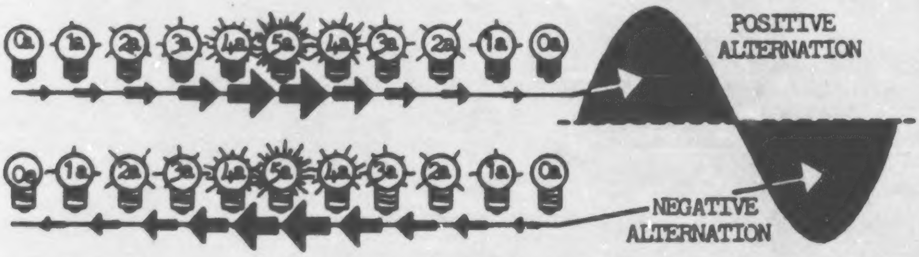
Any change of shape, from the "pure" sine wave, is called "distortion". (Sometimes caused by the author or printer!)

Q-21 a. A "sine wave" is the usual representation of _____ _____.
b. T-F Sine waves have a particular shape.

A-20 a. t_5
b. increasing....up toward the "negative" peak.
c. t_{10}

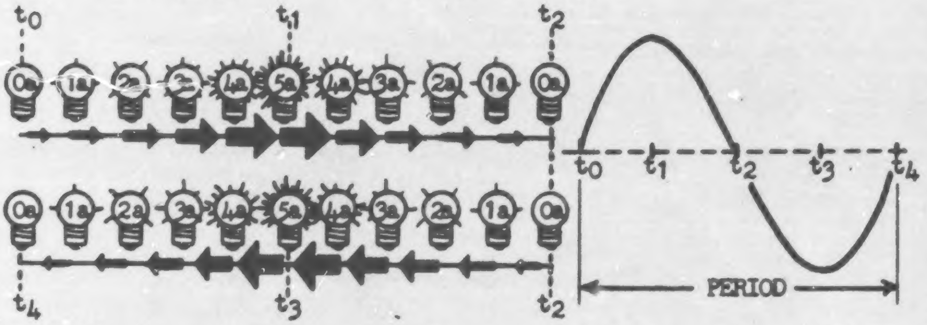
SINE WAVE REPRESENTATION

Alternating Current (AC), is usually represented as a "sine wave". The part of the sine wave above the reference line, represents the "positive" alternation. The part of the sine wave below the reference line, represents the "negative" alternation.



Therefore.....one SINE WAVE, represents one CYCLE!

The reference line itself, represents TIME....tick...tick....



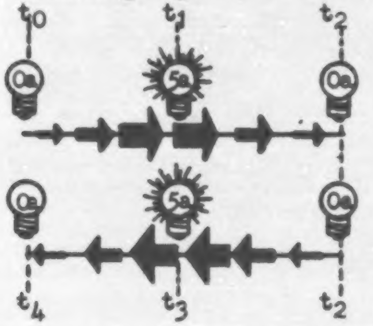
Therefore.....the "period" of this cycle would be from t_0 to t_4!

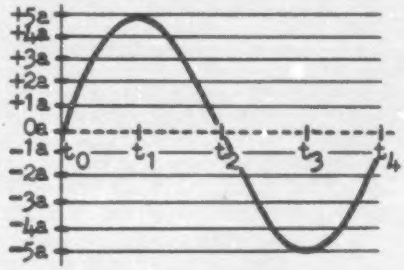
Q-22 a. The "reference line" represents ___________.
b. The portion of the sine wave above the reference line represents the ___________ alternation.
c. The portion of the sine wave below the reference line represents the ___________ alternation.
d. "Time" is represented by the _____________ line.
e. Can you think of another question to ask? ________

A-21
a. Alternating Current
b. True

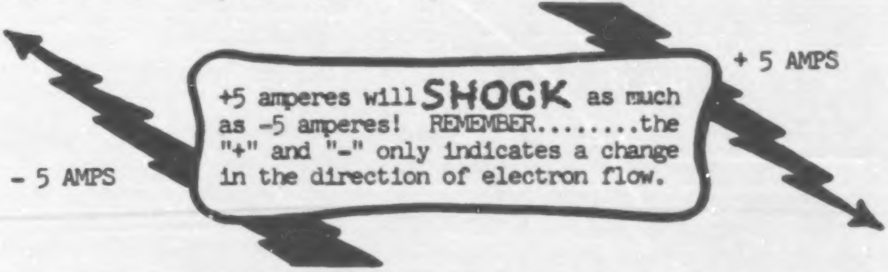
SINE WAVE REPRESENTATION

The horizontal axis of a sine wave (the reference line), represents "time". The vertical axis of a sine wave, represents "amperes of current". Above the reference line, the current is marked as being positive (+). Below the reference line, the current is marked as being negative (-).





The cycle begins at t_0 with 0 amperes. By t_1, the current has reached its positive peak of +5 amperes. By t_2, the current has decreased back to 0 amperes. By t_3, the current has reached its negative peak of -5 amperes. By t_4, the current has once more decreased to 0 amperes. (End of cycle)



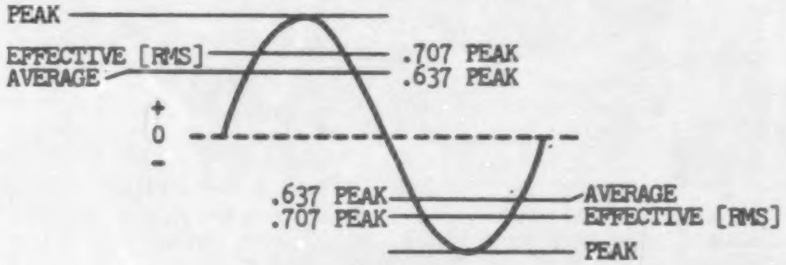
+5 amperes will **SHOCK** as much as -5 amperes! REMEMBER........the "+" and "-" only indicates a change in the direction of electron flow.

Q-23 a. The horizontal axis or "reference line" represents _____.
b. Above the reference line, current is marked ____(+ or -)
c. T-F Negative alternations are below the reference line.
d. T-F Positive alternations will "shock" more than negative alternations, because the current is flowing frontwards.

A-22
a. "time" marching on....tick...tick...tick...tick..etc..
b. "positive" alternation
c. "negative" alternation
d. reference line.
e. I couldn't either!

SINE WAVE REPRESENTATION

The PEAK, EFFECTIVE, and AVERAGE values of the Alternating Current, would be at (approximately) the "levels" shown below.



Equations

EFFECTIVE = .707 PEAK
AVERAGE = .637 PEAK

PEAK = 1.414 EFFECTIVE
PEAK = 1.57 AVERAGE

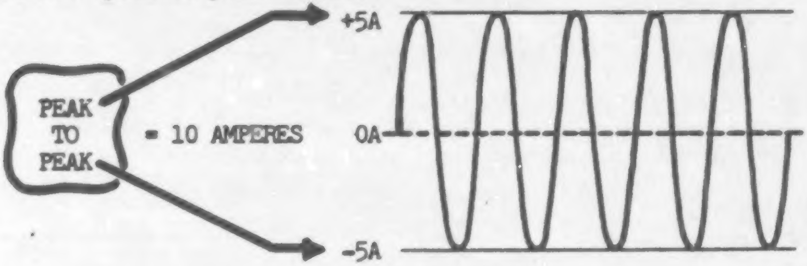
AVERAGE = .9 EFFECTIVE
EFFECTIVE = 1.11 AVERAGE

Q-24
a. If the "peak" current flow thru a central airconditioning system is 20 amperes, the "effective" current = ______?
b. The "name-plate" on an 8 track tape recorder indicates an effective current of 1.2 amps. The "peak" = ______?
c. The effective current of a "video recorder" is 1.5 Amps. Calculate the "average" current. ______
d. An electric range, uses an "average" current of 8 amps. Calculate the "peak" current used by the range. ______
e. A 4 channel Stereo Amplifier is marked as having an RMS current of 2 amperes. Calculate the "peak" current. ______
f. A Radar system having a "peak" current of 60 amperes, has an effective current flow of ______ amperes.
g. An aircraft AC Alternator can produce an average current of 400 amperes. Calculate the "peak" output current. ______
h. The "average" current flow thru a speaker = 800mA. Calculate the RMS current. ______
i. The "peak" output current of a microphone is 50μA. What is the "effective" or RMS output current? ______

A-23 a. time....and also "zero" amperes
b. +
c. True
d. False...the "shock" is the same.

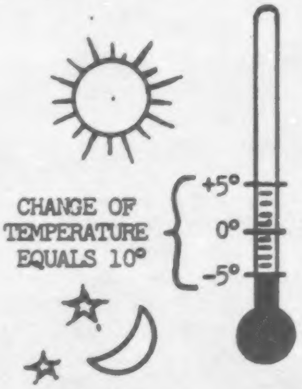
PEAK-TO-PEAK VALUE

When a cycle, (or better, a lot of cycles) is viewed on an Oscilloscope, another "value" of current becomes apparent. It is called the "peak-to-peak" value.



Suppose the temperature (on a Winter day) varied from a high of +5°, to a low of -5°. What was the total "change" of temperature during the day? 10° was the total "change" of temperature.

Many Electronic circuits operate on the total "change" of current, and the "peak-to-peak" value is important to their operation.



Equation PEAK-TO-PEAK = 2 TIMES THE PEAK VALUE

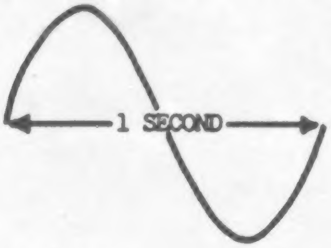
Q-25 a. If the "peak" value of a Radar signal equals 15mA, the "peak-to-peak" value of the signal is ________?
b. The "peak-to-peak" output of a Stereo system = 80mA. What is the "peak" output current? ________
c. The "effective" value of current thru a 100 watt light bulb = 1 ampere. What is the "peak-to-peak" value? ____
d. Calculate the "peak-to-peak" of 5 amperes RMS. ________

A-24 a. 14.14A EFF
b. 1.6968A PK
c. 1.35A AVG
d. 12.56A PK
e. 2.828A PK
f. 42.42A EFF
g. 628A PK
h. 888mA RMS
i. 35.35µA RMS

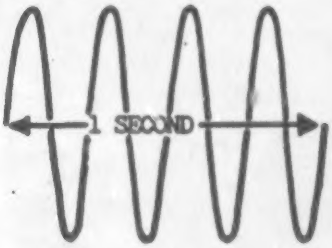
FREQUENCY vs AMPLITUDE

If the frequency (number of cycles per second) is increased, the picture seen on an Oscilloscope changes from......

this



to this.

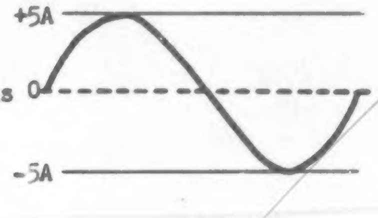


AMPLITUDE [ám-plah-tude]

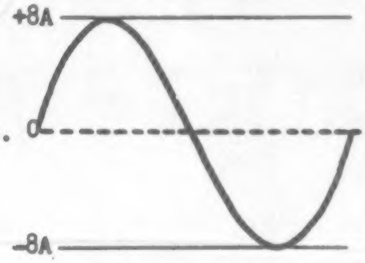
The word "amplitude" means....size....amount....loudness...etc. Increasing the amplitude of a sound, means to make it louder. Increasing the amplitude of a swinging pendulum, means to make it swing back-and-forth a greater distance. Increasing the "amplitude" of an Alternating Current, means to make the "peak" value higher... say from 5 amperes, to 8 amperes. The lamp would get brighter!

Increase the "amplitude" of a cycle seen on an Oscilloscope, and the picture seen changes from......

this



to this.

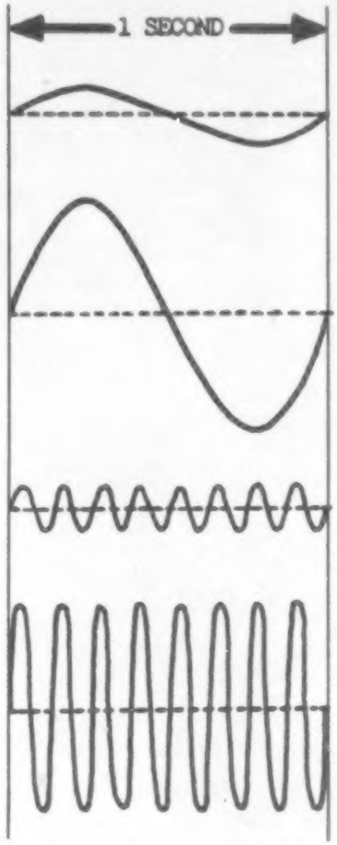


Q-26 a. T-F Increasing the "amplitude" of alternating current means to increase the number of cycles per second.
b. T-F The "amplitude" of the sound from a radio is increased, by turning the volume control "up".
c. Which AC has the largest amplitude? 5A PK or 10A PK-TO-PK

A-25 a. 30mA PK-PK
b. 40mA PK
c. 2.828A PK-PK
d. 14.14A PK-PK

FREQUENCY vs AMPLITUDE

Examine the following pictures, seen on an Oscilloscope.



Low frequency.....Low amplitude.

Low frequency....High amplitude.

High frequency.....Low amplitude.

High frequency....High amplitude.

NOTE: The "frequency" and "amplitude" are independent of each other. "Frequency" is the number of cycles. "Amplitude", is how high the cycles are. How many???...and how high???

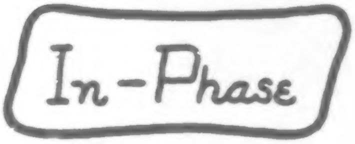
Q-27 a. T-F If the frequency is increased, the amplitude also increases.
b. T-F If the amplitude is increased, the frequency will remain the same.
c. T-F Double the frequency, and the amplitude also doubles.

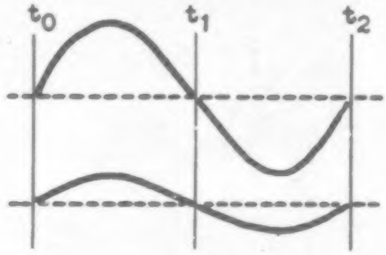
A-26
a. False....it means to increase the "peak" value of the existing cycles.
b. True...."up" meaning louder.
c. They both have the same "amplitude"...5A PK = 10A PK-PK

IN-PHASE and OUT-OF-PHASE

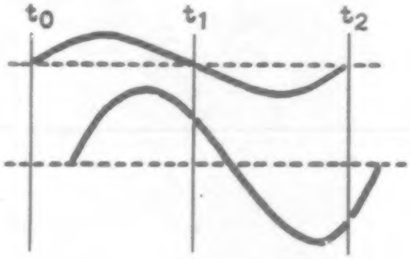
A city park.....playground.....swings.....two kids on swings. If they are going up-and-down together, they are said to be swinging "in-phase". If they do NOT go up-and-down together, they are said to be "out-of-phase".

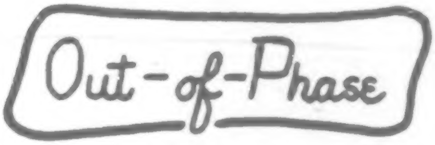
If two sine waves (or cycles) rise-and-fall together, they are said to be "in-phase". Regardless of their "amplitudes", they MUST cross the reference line, at the same moment of time.





If two sine waves (or cycles) DO NOT rise-and-fall together, they are said to be "out-of-phase". They DO NOT cross the reference line at the same moment of time.





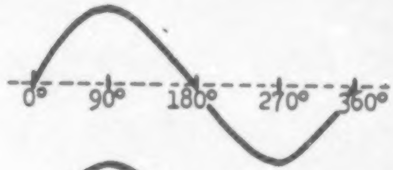
Q-28 a. "In-phase" sine waves must cross the __________ line at the same moment of ______.

A-27 a. False....it means you get more cycles, at the same amplitude (or peak value).
b. True.....it means the peak value of the existing cycles is being made higher.
c. False....see (a) above.

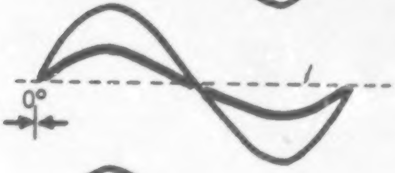
DEGREES OUT-OF-PHASE

Recall..... a "cycle" (or sine wave) is also measured in degrees. It begins at 0°, and ends at 360°. The "phase difference" between two sine waves, is often measured in degrees. See below....

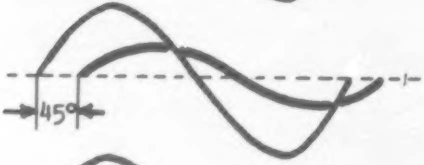
360°



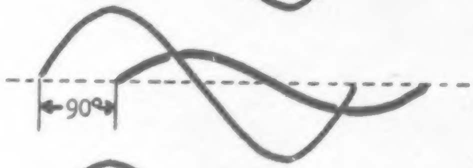
Here are two sine waves, "in-phase".



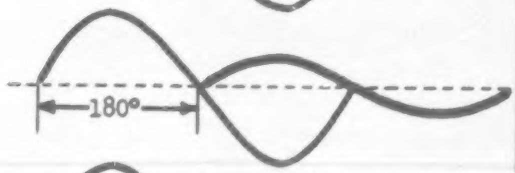
Here they are 45°degrees out-of-phase.



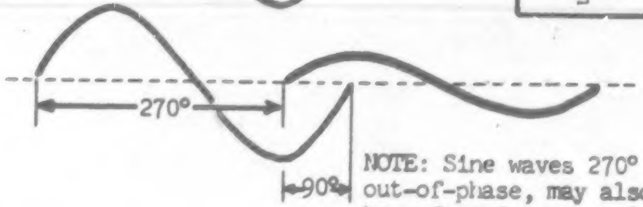
Here they are 90 degrees out-of-phase.



Here they are 180 degrees out-of-phase.



Here they are 270°degrees out-of-phase. (See NOTE:)



NOTE: Sine waves 270° out-of-phase, may also be referred to as 90° out-of-phase.

IMPORTANT!!!

A difference in "phase" between two sine waves, means there is a "time" difference between their "peak" currents. Sine waves (or cycles), can be made any "time difference" apart, by sending them thru special Electronic circuits, which will be studied later in this course.

INFORMATIONAL PAGE ONLY....Not for study

A-28
a. reference line....moment of time.

WAVELENGTH

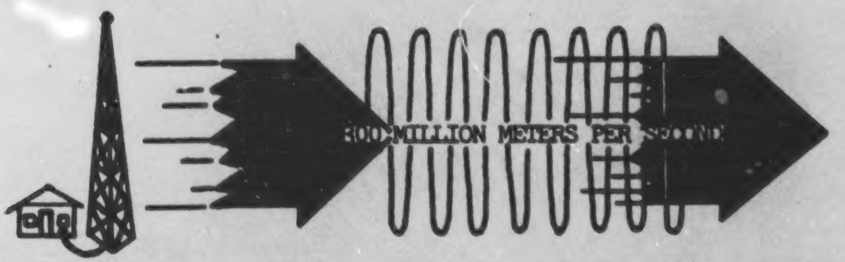
Light waves travel thru space at a speed of about 186,000 miles per second. If a flashlight is turned "on", it would be one second, before someone 186,000 miles away sees the light. To the moon, it would take about 1.3 seconds (239,000 miles). A burst of light from the sun, takes about 500 seconds to reach the earth (93,000,000 miles).

There are 5,280 feet in a mile. That's 1,760 yards. 186,000 miles then, equals 327,360,000 yards. A "meter" is about a yard long. (39.37 inches) Therefore, light travels about 300,000,000 meters in one second (299,776,000 meters per second).

Radio, Television, Radar, Microwaves, etc., all travel at the same speed as light waves.

Radio Wave Velocity 300,000,000 METERS PER SECOND

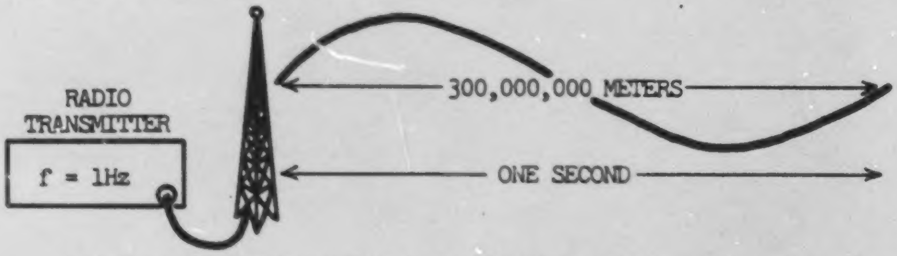
Once a radio wave has left the "transmitting" antenna, its velocity remains the same (300,000,000 meters per second) as it travels thru space.



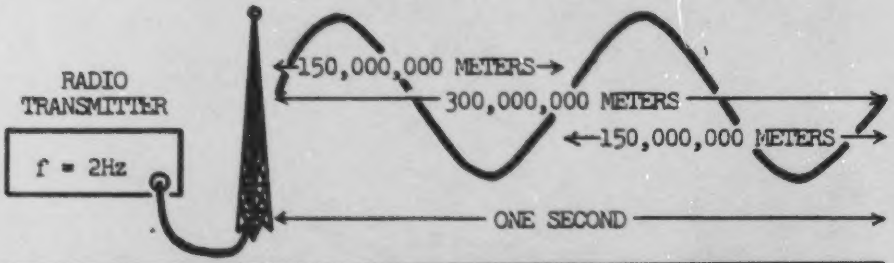
Q-29 a. T-F Radio waves and Light waves travel at the same speed.
b. Radio wave velocity = ____________ miles per second.
c. Radio wave velocity = ____________ meters per second.

WAVELENGTH

Consider for a moment, a radio "transmitter" operating at a frequency of 1 cycle per second. In one second, how many cycles are produced? Of course....one! Allow that cycle to "radiate" from an antenna. When the beginning of the cycle leaves the antenna, it starts traveling at a speed of 300 million meters per second. One second later, the end of the cycle will be leaving the antenna. Question??? How far away will the beginning of the wave be, when the end of the wave is leaving the antenna? Well.....the cycle is one second long.....the beginning of the cycle will travel a distance of 300 million meters in one second.....therefore, the beginning of the wave will be 300,000,000 meters away, when the end of the wave is just leaving the antenna.....one second away!



Increase the frequency to 2 cycles per second. How many cycles are produced in one second? Two! How many cycles will be "radiated" from the antenna in one second? Two! How many meters long, is either of the waves? 150,000,000 meters!

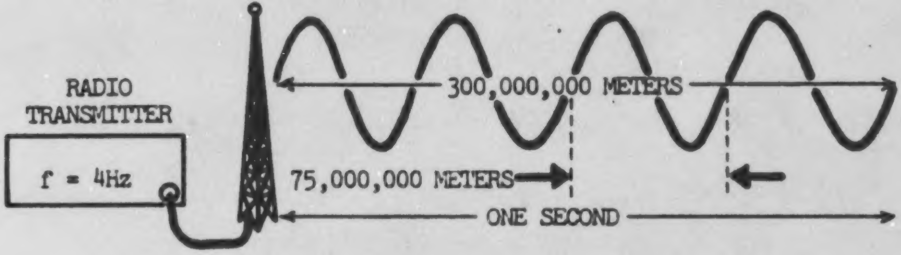


Q-30 a. T-F The radio wave gets shorter, as frequency increases.

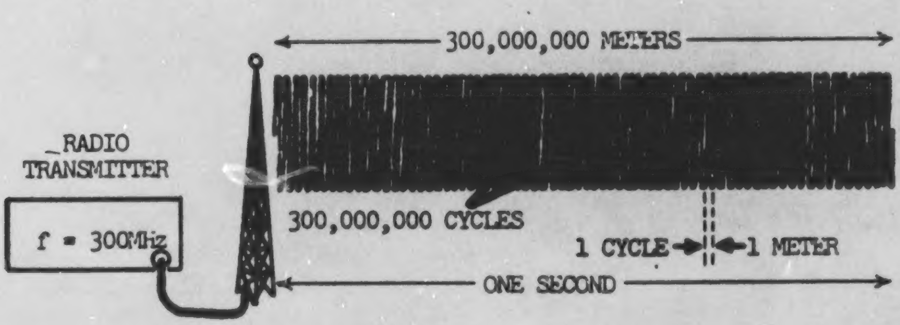
A-29 a. True
b. 186,000 .....and that converts to 669,600,000 Miles Per Hr.
c. 300,000,000 ..."faster than a speeding bullet....."

WAVELENGTH

Increase the frequency to 4 cycles per second. How many cycles are produced in one second? Four! How many cycles will be "radiated" from the antenna in one second? Four! How many meters long is any one of the four cycles? 75,000,000 meters!



Increase the frequency to 300 million cycles per second (300MHz). How many cycles are produced in one second? 300,000,000! How many cycles will be "radiated" from the antenna in one second? 300,000,000! How many meters long is any one of the 300,000,000 cycles? 1 meter!



IMPORTANT! Notice that as the frequency is increased, the physical length of each cycle of a radio wave gets shorter.

Q-31 a. As the frequency increases, the length of each cycle of the radio wave gets ____________(longer or shorter).
b. Radio wave velocity = ________________ meters per second.

A-30 a. True....if you can call 150,000,000 meters "shorter".

WAVELENGTH

The "physical length" of any one cycle of a radio wave, is called the WAVELENGTH (Symbol λ ....the Greek letter "lamda")

Wavelength (λ)

The PHYSICAL LENGTH of any one cycle of a radio wave. It is usually measured in meters, centi-meters, or milli-meters.

The WAVELENGTH (λ) of a radio wave, depends upon the frequency of the wave, and the "velocity" of the wave. The frequency can be changed, but the "velocity" cannot. It is a constant 300 million meters per second. The WAVELENGTH (λ) can be calculated by.......

Equation

$$\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{FREQUENCY}} \qquad \boxed{\lambda = \frac{v}{f}}$$

EXAMPLE: Calculate the "wavelength" of a radio wave having a frequency of 1.5MHz (1,500,000 cycles per second).

$$\text{WAVELENGTH} = \frac{\text{VELOCITY}}{\text{WAVELENGTH}} \quad \lambda = \frac{v}{f} = \frac{300,0\cancel{0}\cancel{0},\cancel{0}\cancel{0}\cancel{0}}{1,5\cancel{0}\cancel{0},\cancel{0}\cancel{0}\cancel{0}} = 200 \text{ METERS}$$

1.5MHz (1500KHz) would be the operating frequency of an AM Radio station on the high end of the dial. Each wave is 200 meters long!

Q-32 a. What would be the "wavelength" of each cycle of a Channel 3 TV signal at 60MHz (60,000,000Hz)? ________ meters.
b. Calculate the wavelength of each cycle of a Police radio at 150MHz. (150,000,000Hz) ________ meters.
c. Calculate the wavelength of a Loran navigation signal, operating at 100KHz. (100,000Hz) ________ meters.
d. What is the "wavelength" of each cycle of a Citizens Band station, operating near 30MHz (30,000,000Hz) ________
e. The National Bureau of Standards WWV, operates a radio station at 20MHz. Calculate the wavelength of one cycle.
f. What is the "wavelength" of one cycle of a UHF TV station operating at 600MHz? ________
g. European power, at a frequency of 50Hz, has a wavelength of ________ meters.

A-31 a. shorter....even down to milli-meters, and micro-meters.
b. 300,000,000 (300 Million Meters Per Second)

WAVELENGTH

If the wavelength (λ) of a radio wave is known, the frequency (f) of the wave can be determined.

Equation

$$\text{FREQUENCY} = \frac{\text{VELOCITY}}{\text{WAVELENGTH}} \qquad \boxed{f = \frac{v}{\lambda}}$$

EXAMPLE: What is the operating frequency (f) of a Radio Station, if its wavelength (λ) equals 200 meters?

$$\text{FREQUENCY} = \frac{\text{VELOCITY}}{\text{WAVELENGTH}} \qquad f = \frac{v}{\lambda} = \frac{300{,}000{,}0\cancel{0}\cancel{0}}{2\cancel{0}\cancel{0}} = 1{,}500{,}000 \text{ Hertz}$$

(1500KHz or 1.5MHz)

Many "short-wave" radios have their dials marked in "meters", rather than "hertz". Often, overseas Broadcasting Stations, discuss their "meter band", rather than their "frequency band" of operation.

Amateur Radio "ham" operators talk of their equipment as "20 meter", or "40 meter", "80 meter", "2 meter", "10 meter", etc.. Radar equipment is often called "10 centimeter" (3GHz), or "3 centimeter" (10GHz), etc.. Some skill, in the conversion from wavelength to frequency, should be developed.

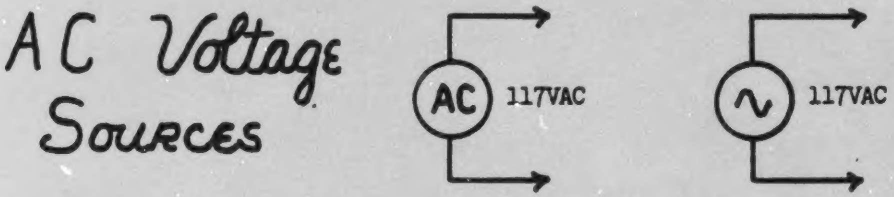
Q-33 a. If the wavelength of each cycle equals 5000 meters, the frequency of the radio wave equals __________.
b. A Voice of America Broadcasting Station has a wavelength of 30 meters. What is its broadcasting frequency? ______
c. What is the frequency of a wave, if the wavelength of each cycle equals 5,000,000 meters? __________
d. What is the frequency of an Amateur Radio Station, operating in the 2 meter band? __________
e. What is the "dial" reading of an FM Stereo station, if the wavelength of each cycle equals 3 meters? __________
f. The wavelength of a "May Day" (S-O-S) emergency call is 150 meters. What is the frequency of the station? ______
g. T-F If the frequency increases, the wavelength decreases.
h. T-F Frequency and wavelength are "independent" of each other.

A-32
a. 5 meters
b. 2 meters
c. 3000 meters (3KM)
d. 10 meters
e. 15 meters
f. .5 meter (1/2 meter-50cm)
g. 6 million meters long!

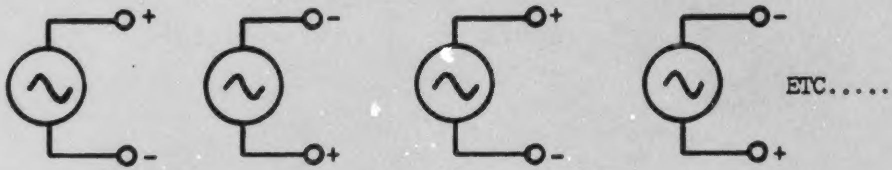
AC VOLTAGE

There are many sources of AC Voltage. Some of them are...... AC Generators (Alternators), Oscillators, Multivibrators, DC to AC Converters, etc.. (Sorry....there are no AC batteries!)

These sources of AC Voltage have several schematic symtols:



To produce an alternating "current", the POLARITY of the AC Voltage source reverses, each alternation.......



AC Voltages are represented as "sine-waves". They also have peak-to-peak, peak, effective, and average values. The equations to calculate these values, remain the same as for AC Currents....

EFFECTIVE = .707 PEAK
AVERAGE = .637 PEAK
PEAK = 1.414 EFFECTIVE
PEAK = 1.57 AVERAGE
EFF = 1.11 AVG
AVG = .9 EFF
PEAK-TO-PEAK = 2 TIMES THE PEAK

Q-34
a. Calculate the "effective" voltage of an AC power source of 50V PK. ______________
b. If the PK-TO-PK value equals 16 volts, the effective voltage = ______________.
c. What is the PK-PK value of 10 volts "average"? ______________
d. If the PK-PK value equals 4 volts, what is the RMS value? ______________
e. Effective = 30VAC. Calculate the "average" value. ______________

A-33
a. 60,000Hz (60KHz)
b. 10 Mega Hertz (10MC)
c. 60Hz (USA power)
d. 150 Mega Hertz (150MC)
e. 100 Mega Hertz (100MC)
f. 2 Mega Hertz (2MC)
g. True...decrease = shorter.
h. False... $f\uparrow$ $\lambda\downarrow$

AC VOLTAGE

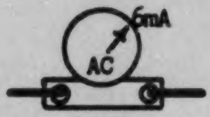
All AC Voltages are assumed to be the "effective" value, unless otherwise specifically stated.

Repeat!

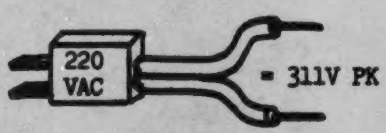
All AC Voltages (and currents), are assumed to be the "effective" value, unless otherwise specifically stated!

This means that all meters (Voltmeters and Ammeters), are calibrated to "read-out" the effective value. All voltage and current indications on schematic diagrams, are to be assumed to be the "effective" value, unless otherwise marked.

Effective Readings



An electrical wall outlet, may be marked 117VAC. This therefore, is the "effective" value. How high does the actual "peak" value go? 1.414 (117V) = 165 VOLTS PEAK! An air-conditioner may be marked 220VAC. This therefore, is the "effective" value. How high is the actual "peak" value? 1.414 (220V) = 311 VOLTS PK!



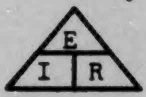
Q-35 a. An AC voltmeter indicates 120V. The peak-to-peak value equals _______________.
b. An AC ammeter reads 5mA. The "peak" value = __________.

A-34
a. 35.35V EFF
b. 5.656V EFF
c. 31.4V PK-PK
d. 1.414V RMS or EFF
e. 27V AVG

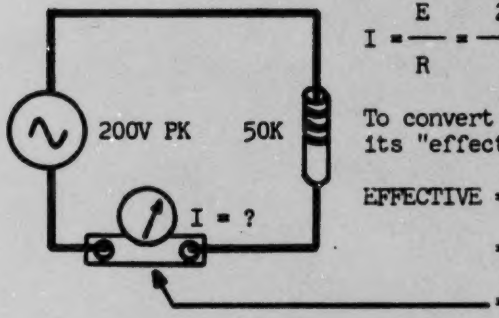
OHM'S LAW

Ohm's Law calculations for an AC Circuit, are the same as for a DC Circuit. E = Voltage I = Current R = Resistance

Equations $E = I \cdot R$ $I = \frac{E}{R}$ $R = \frac{E}{I}$



EXAMPLE: Calculate the "effective" current flowing in the following circuit. (Note: The voltage is given as "peak".)



$$I = \frac{E}{R} = \frac{200V\ PK}{50K\Omega} = 4mA\ PEAK$$

To convert the 4mA Peak Current, to its "effective" meter reading......

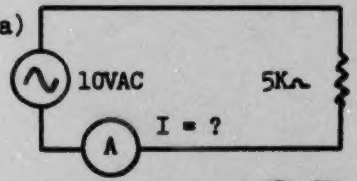
EFFECTIVE = .707 PEAK

= .707 (4mA)

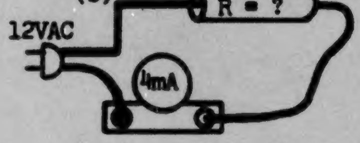
= 2.828 mA EFFECTIVE

Q-36 Solve the following circuits as indicated.

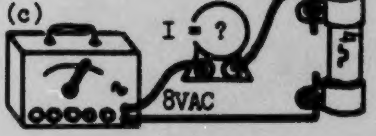
(a)



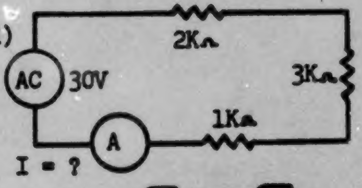
(b)



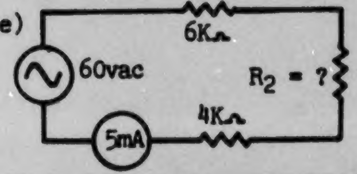
(c)



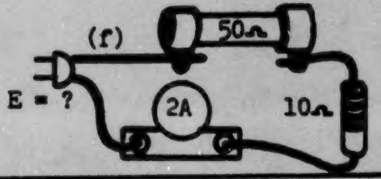
(d)



(e)



(f)



A-35 a. 339.36V PK-PK b. 7.07mA PK

NEW TERMS and EQUATIONS

Although this text began simple enough, it should now be apparent that a lot of "new stuff" has been discussed. Below, is a listing of the material covered. On the following page, there is a Summary Quiz, which will use this list for answers.

TERMS

a. Alternating Current (AC)
b. Alternation
c. Cycle
d. Positive Alternation
e. Negative Alternation
f. Frequency
g. Cycles Per Second
h. Hertz
i. Audio Frequencies
j. Power Frequencies
k. Ultrasonic Frequencies
l. Radio Frequencies
m. Microwaves
n. Frequency Spectrum
o. Kilo Hertz
p. Mega Hertz
q. Giga Hertz
r. Period
s. Instantaneous Values
t. Peak Value
u. Peak-To-Peak Value
v. Effective Value
w. Average Value
x. RMS Value
y. 0° to 360°
z. t_1, t_2, t_3, etc.
aa. Sine Wave
bb. Reference Line
cc. Amplitude
dd. In-Phase
ee. Out-Of-Phase
ff. AC Voltage
gg. 300,000,000
hh. Wavelength

EQUATIONS

1. EFFECTIVE = .707 PEAK
2. AVERAGE = .637 PEAK
3. PEAK = 1.414 EFFECTIVE
4. PEAK = 1.57 AVERAGE
5. AVERAGE = .9 EFFECTIVE
6. EFFECTIVE = 1.11 AVERAGE

7. $f = \frac{1}{t}$ 8. $t = \frac{1}{f}$

9. $\lambda = \frac{v}{f}$ 10. $f = \frac{v}{\lambda}$

A-36
a. 2mA
b. 3K
c. 2A
d. 5mA
e. 2K
f. 120VAC

SUMMARY QUIZ

Q-37 Using the list of TERMS and EQUATIONS, select the best answers for the following. Some terms may be used more than once....some, not at all.

TERMS

___ 1. Electrical current which is "constantly changing in amplitude and periodically reversing in direction".
___ 2. One million cycles per second.
___ 3. Two sine waves, "rising-and-falling" together.
___ 4. 20Hz to 20KHz.
___ 5. The maximum current reached during any alternation.
___ 6. This is another name for the "effective" value.
___ 7. The length of any one cycle of a Radio wave.
___ 8. One thousand cycles per second.
___ 9. Degrees of a sine wave.
___10. The same heating effect, as an equal amount of DC.
___11. Each cycle contains two of these.
___12. The time required to complete any one cycle.
___13. A line, representing "time".
___14. 1 Giga Hertz and "up".
___15. International unit of measure for "frequency".
___16. The velocity, in meters per second, of a radio wave.
___17. Time "indicators".
___18. One Billion Cycles Per Second.
___19. 50Hz, 60Hz, and 400Hz.
___20. Follows each positive alternation.
___21. Obtained from an AC power source, such as a wall outlet.
___22. 20KHz up to 300GHz.
___23. Contains 180°
___24. The most common representation of alternating current.
___25. Sound waves, too high in frequency to hear.
___26. When two sine waves are not "rising-and-falling" together.
___27. Positive "peak" to the negative "peak".
___28. The period, is the length of time to complete one of these.
___29. Increase this, and the "peak" becomes higher.
___30. A list of frequencies, from "low" to "high".

EQUATIONS

___ a. Want to convert from the RMS value to the "peak" value.
___ b. Want to calculate the time necessary to complete one cycle.
___ c. Given the "effective", and want to know the "peak".
___ d. Want to calculate the length of one cycle of a radio wave.
___ e. Given the "average" and want to know the "effective".
___ f. Given the "period", and want to calculate "frequency".
___ g. Know the RMS value, and want to calculate the "peak" value.
___ h. Given the "wavelength, and want to know the "frequency".

A-37 These are the "best" answers (though you may not agree).

1. a
2. p
3. dd
4. i
5. t
6. x
7. hh
8. o
9. y
10. v
11. b
12. r
13. bb
14. m
15. h
16. gg
17. z
18. q
19. j
20. e
21. ff
22. l
23. b, d, or e
24. aa
25. k
26. ee
27. u
28. c
29. cc
30. n

EQUATIONS

a. 3
b. 8
c. 3
d. 9
e. 6
f. 7
g. 3
h. 10

SUMMARY

The study of Alternating Current and the Frequency Spectrum, should not end here. Publications on these subjects are available in Technical Study Centers.

Beginning with a "simple" reversing of current, a wide variety of facts and figures began to emerge. Alternations and cycles were easy enough, but then along came "period" and "frequency" and all their calculations. Then suddenly, there were all kinds of frequencies!

Peak values were simple. But then came instantaneous, effective, average, and peak-to-peak values, and all their calculations. Things settled down for a moment, only to be interrupted by Radio Wave velocity, wavelength, and their calculations. And it all ended with Ohm's Law.

Quite a "bite-to-chew", this Alternating Current! Fortunately, all the terms studied here will become a part of your new language, to be used over-and-over as Electronics continues.

Alternating Current and the Frequency Spectrum.....AC Electronics!

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-12

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 12

CAPACITORS AND CAPACITIVE REACTANCE

March 1976

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

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Radar Principles Branch
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1 March 1976

ELECTRONIC PRINCIPLES

MODULE 12

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

TITLE	PAGE
Overview	i
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Adjunct Guide	1
Laboratory Exercise, 12-1	7
Module Self Check	9
Answers	11

OVERVIEW

CAPACITORS AND CAPACITIVE REACTANCE

1. SCOPE: This module will define capacitance, show the construction of capacitors and explains their characteristics in electronic circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a group of statements, select the ones which describe the physical characteristics of a capacitor.

b. From a group of statements, select the ones which describe the electrical characteristics of a capacitor.

c. From a group of statements, select the one which describes the phase relationship of current and voltage in a capacitor.

d. Given a list of statements, select the ones which describe the effect of varying frequency and capacitance on capacitive reactance.

e. Given the signal frequency, formulas, and the value of three capacitors in a series-parallel configuration, compute the total capacitance and total capacitive reactance.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preferences, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

AUDIO-VISUAL:

Supersedes KEP-GP-12, 1 August 1975.

Television lesson, Capacitors and Capacitive Reactance, TVK 30-255

LABORATORY EXERCISE:

Capacitors and Capacitive Reactance, 12-1

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

ADJUNCT GUIDE

Instructions:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text, Volume II, and read paragraphs 2-1 thru 2-40. Return to this page and answer the following questions.

1. A capacitor physically consists of:

_____ a. plates and conductors.

_____ b. plates and iron.

_____ c. dielectric and plates.

_____ d. non-conductors and dielectric.

2. To decrease the capacitance of a capacitor, you can

_____ a. increase plate area.

_____ b. decrease applied voltage.

_____ c. decrease the plate area.

_____ d. decrease the thickness of the dielectric.

3. Capacitance increases if you

_____ a. move the plates closer together.

_____ b. decrease plate area.

_____ c. move the plates farther apart.

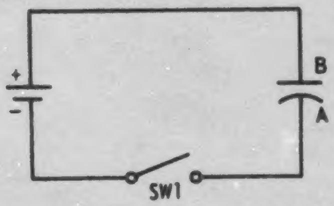
_____ d. increase dielectric thickness.

4. A capacitor stores electrical energy in an

_____ a. electromagnetic field.

_____ b. electrostatic field.

5. If the capacitor has no charge and SW1 is closed, the electrons are:



REP4-951

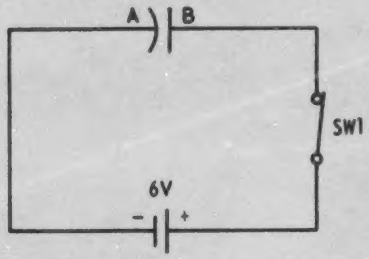
_____ a. pulled off plate A.

_____ b. pulled off plate B.

_____ c. forced onto plate A.

_____ d. forced onto plate B.

6. Plate A has a negative charge and plate B has a positive charge, then



REP4-952

_____ a. a difference of potential exists between the two plates.

_____ b. electrostatic lines of force are directed from plate A to plate B.

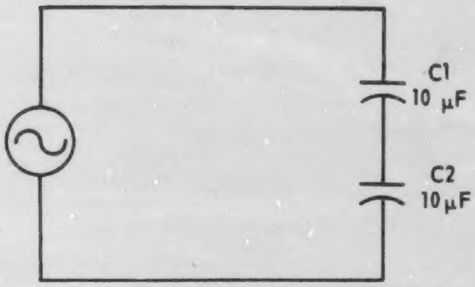
_____ c. electrostatic lines of force are directed from plate B to plate A.

CONFIRM YOUR ANSWERS

B. Turn to Student Text, Volume II, and read paragraphs 2-41 thru 2-46. Return to this page and answer the following questions.

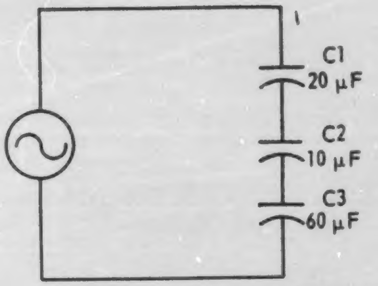
1. Find the total capacitance for each circuit.

a. C_t = ________ µF



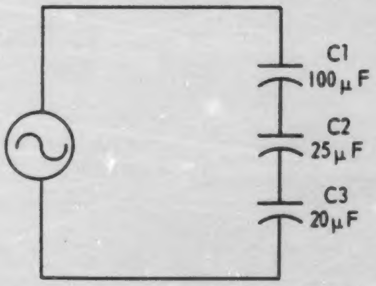
REP4-953

b. C_t = ________ µF



REP4-954

c. C_t = ________ µF.



REP4-955

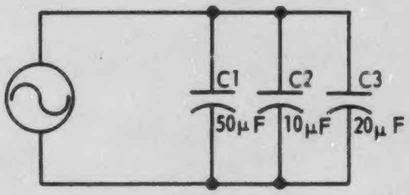
2. When capacitors are wired in series, total capacitance (increases)(decreases).

CONFIRM YOUR ANSWERS

C. Turn to Student Text, Volume II, and read paragraphs 2-47 thru 2-49. Return to this page and answer the following questions.

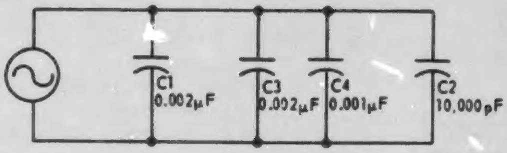
1. Find the total capacitance for each circuit.

a. C_t = ________ µF



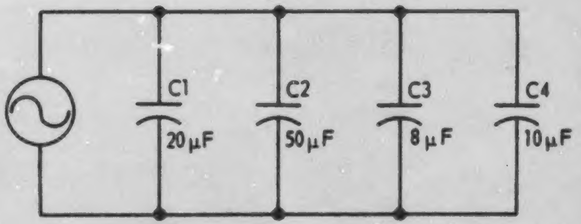
REP4-956

b. C_t = ________ µF.



REP4-957

c. C_t = ________ µF.



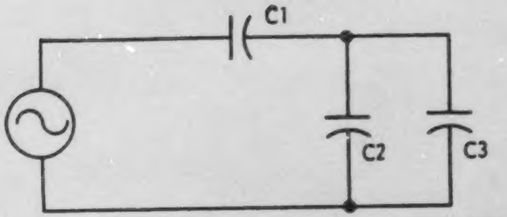
REP4-958

2. When capacitors are wired in parallel, total capacitance (decreases) (increases).

CONFIRM YOUR ANSWERS

D. Turn to Student Text, Volume II, and read paragraphs 2-50 thru 2-53. Return to this page and answer the following questions.

1. To find the C_t for the series-parallel network shown,

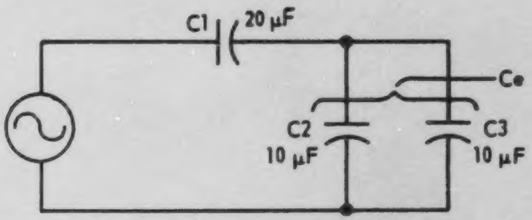


REP4-955

_____ a. add C1, C2, and C3 directly.

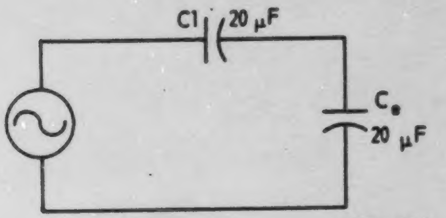
_____ b. use the reciprocal method to find the equivalent capacitance of C2 and C3 and add this value directly to C1.

_____ c. add C2 and C3 directly and use the reciprocal method to find the equivalent capacitance of this sum and C1.



REP4-960

2. To solve the above series-parallel capacitive circuit for C_t, the first step is to determine the equivalent capacitance (C_e) of the parallel network.



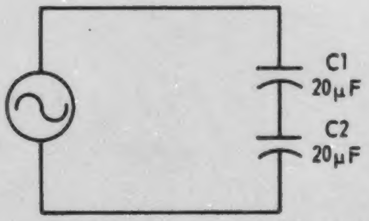
REP4-961

The next step is to combine C_e with C1.

C_t for this circuit is ________ μF.

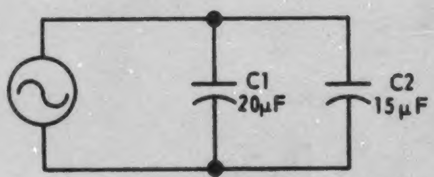
3. Solve for C_t in each of the circuits below:

a. C_t = ________ μF.



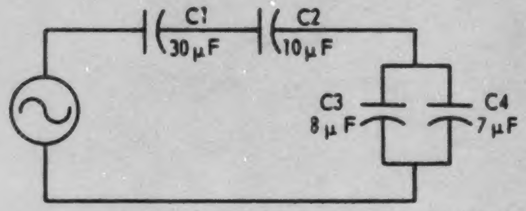
REP4-962

b. C_t = ________ μF.



REP4-963

c. C_t = ________ μF



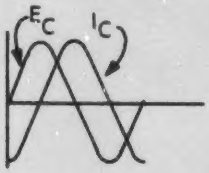
REP4-964

CONFIRM YOUR ANSWERS

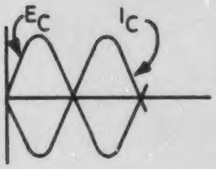
E. Turn to Student Text, Volume II, and read paragraphs 2-54 thru 2-71. Return to this page and answer the following questions.

1. Mark the drawing that identifies the correct phase relationship of current and voltage in a pure capacitive circuit.

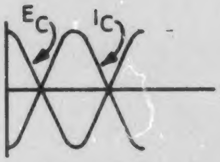
a.



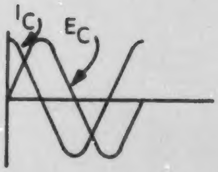
b.



c.



d.



REP4-965

2. The phase relationship in a pure capacitor is such that the capacitor current (lags) (leads) the applied voltage by 90°.

CONFIRM YOUR ANSWERS

F. Turn to Student Text, Volume II, and read paragraphs 2-72 thru 2-94. Return to this page and answer the following questions.

1. The opposition a capacitor offers to alternating current is called ______________ reactance.

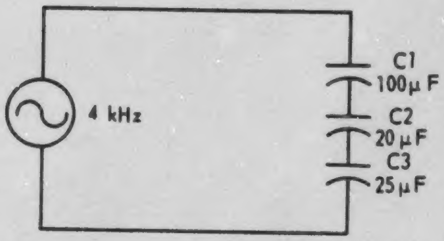
2. The symbol for this reactance is ________ and is measured in ______________.

3. The two variables which affect reactance are ______________ and ______________ ______________ of the circuit.

4. Given the signal frequency and value of capacitors in series, compute C_t and X_{C_t} of each circuit below.

a. $$C_t = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

$$X_{C_t} = \frac{.159}{fC}$$

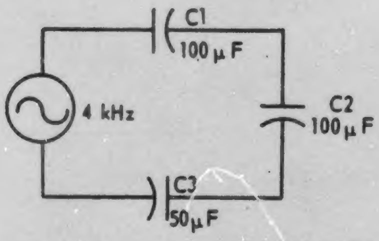


REP4-966

C_t = ______________ μF

X_{C_t} = ______________

b.

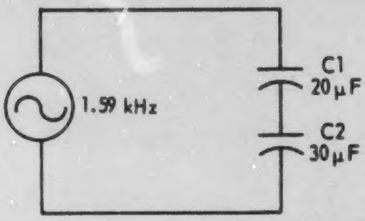


REP4-967

C_t = ______________ μF

X_{C_t} = ______________

c.



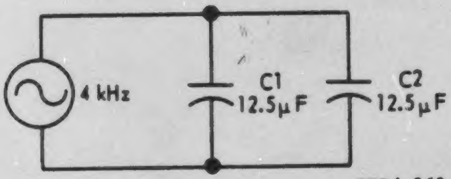
REP4-968

C_t = ______________ μF

X_{C_t} = ______________

5. Given the signal frequency and value of capacitors in parallel, compute the total capacitance and total reactance.

a.

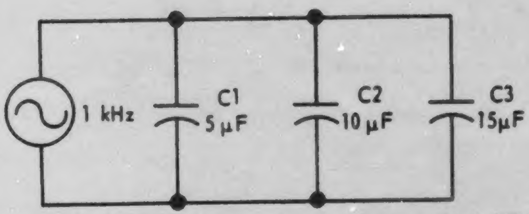


REP4-969

C_t = ______________ μF

X_{C_t} = ______________

b.



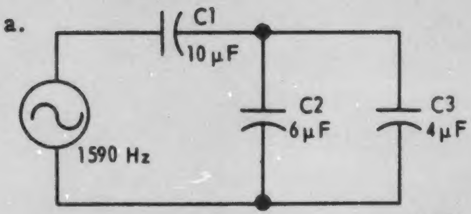
REP4-970

C_t = ______________ μF

X_{C_T} = ______________

6. Given the signal frequency and the value of capacitors in a series-parallel configuration, compute the total capacitance and total capacitive reactance for each circuit below.

a.

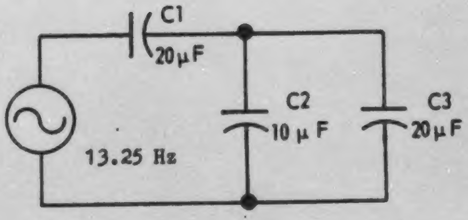


REP4-971

C_t = ______________ μF

X_{C_t} = ______________

b.

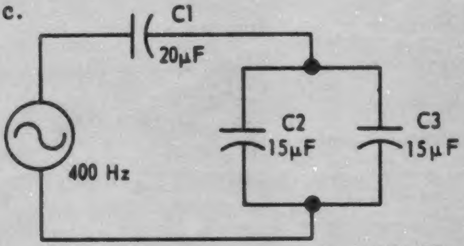


REP4-972

C_t = ______________ μF

X_{C_t} = ______________

c.



REP4-973

C_t = ______________ μF

X_{C_t} = ______________

CONFIRM YOUR ANSWERS

G. Turn to Student Text, Volume II, and read paragraphs 2-95 thru 2-100. Return to this page and answer the following questions.

1. The compression type variable capacitor has a dielectric of

_____ a. air.

_____ b. paper.

_____ c. mica.

_____ d. oil.

2. The rotor-stator variable capacitor varies capacitance by changing the

_____ a. distance between the plates.

_____ b. effective area of the plates.

_____ c. dielectric constant.

_____ d. thickness of the dielectric.

3. Match each of the fixed capacitors with the corresponding statements.

CAPACITOR	STATEMENT
a. _____ Electrolytic	1. Low cost and small size.
b. _____ Oil	2. Used in high power transmitter circuits.
c. _____ Mica	3. Uses oxide film for dielectric.
d. _____ Ceramic	4. Has high dielectric strength and silver plates.
e. _____ Paper	5. Low capacitance - high frequency component.

CONFIRM YOUR ANSWERS

H. Turn to Laboratory Exercise 12-1. This exercise will increase your knowledge of capacitors and help you gain experience working with these components.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

LABORATORY EXERCISE 12-1

OBJECTIVES:

1. Determine what effect a change in voltage has on a capacitive circuit.

2. Determine what effect a change in frequency has on a capacitive circuit.

3. Determine what effect a change in capacitance has on a capacitive circuit.

EQUIPMENT:

1. AC Inductor and Capacitive Trainer 5967.

2. Multimeter AN/PSM-6.

3. Sine-Square Wave Generator 4864.

4. Meter Panel (0-10, 50, 250 AC mA) 4568.

REFERENCE:

Student Text, Volume II, paragraphs 2-41 thru 2-100.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

A. Preparation of the trainer and test equipment.

1. PSM-6

(a) FUNCTION switch - ACV

(b, RANGE switch - 50

2. AC Inductor and Capacitive Trainer placed on T-bench before you.

3. Sine Wave Generator

(a) Plug into 110 volt source.

(b) SQUARE WAVE AMPLITUDE control-slightly clockwise (CW) to ON position.

(c) SINE WAVE AMPLITUDE control - 0.

(d) SINE WAVE RANGE control - 10V.

(e) FREQ MULTIPLIER control - 10.

(f) FREQUENCY (CPS) dial - 50.

B. Determine what effect a change in voltage has on a capacitive circuit.

1. Connect the capacitive circuit as shown in figure 1-1.

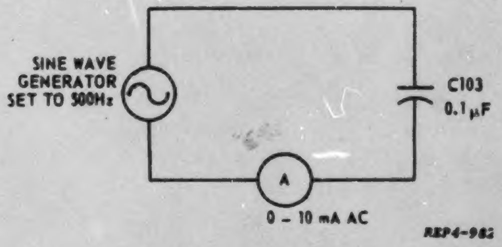


Figure 1-1

2. Set the frequency of the sine wave generator to 500 Hz. (FREQ MULTIPLIER to 10 and FREQUENCY dial to 50.) DO NOT TOUCH the frequency controls during the remainder of this objective.

3. Adjust the amplitude of the sine wave output to 6 VAC at the output terminals of the sine wave generator. Measure with the PSM-6.

4. Read and record the circuit current.

Frequency at 500 Hz, $E_a = 6$ V,

$I_t =$ ______________________ mA

5. Adjust the amplitude of the sine wave output to 8 VAC at the output terminals of the sine wave generator.

Frequency at 500 Hz, $E_a = 8$ V,

$I_t =$ ______________________ mA

6. An increase in E_a in a series capacitive circuit will have what effect on circuit curre

_____ a. Remain the same.
_____ b. Decrease.
_____ c. Increase.

7. The current change was produced by a change in

______ a. Resistance.

______ b. Capacitance.

______ c. Capacitance Reactance.

______ d. Voltage.

CONFIRM YOUR ANSWERS.

C. Determine what effect a change in frequency has on a capacitive circuit.

1. Using the circuit in figure 1-1, adjust the amplitude of the sine wave until the output is 8 V AC at the output terminals of the sine wave generator.

NOTE: DO NOT TOUCH the amplitude control during the remainder of this objective.

2. Set the output of the sine wave generator to each of the frequencies listed and record the current.

FREQUENCY	CIRCUIT CURRENT
200 Hz	______ mA
300 Hz	______ mA
400 Hz	______ mA

3. In a series capacitive circuit an increase in frequency will (increase)(decrease) circuit current.

4. In a capacitive circuit the current change produced by a change in frequency is produced by a change in

______ a. Capacitance.

______ b. Resistance.

______ c. Reactance.

______ d. Voltage.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

D. Determine the effect of a change in the capacitance in a capacitive circuit.

1. Connect circuit as shown in figure 1-2.

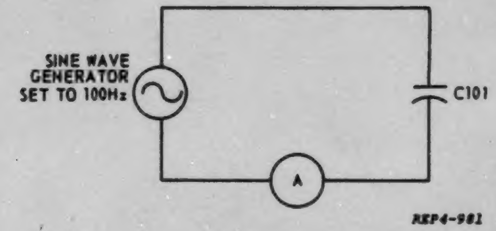


Figure 1-2

2. Set the frequency of the generator to 100 Hz. Set C101 to .5μF.

3. Adjust sine wave amplitude until the ammeter indicates 4 mA. DO NOT CHANGE the FREQUENCY or AMPLITUDE controls during the remainder of this objective.

4. Set C101 to the values shown and record the circuit current.

C101 SETTING	CIRCUIT CURRENT
(1) .5μF	______ mA
(2) .4μF	______ mA
(3) .3μF	______ mA
(4) .6μF	______ mA

5. A decrease in capacitance in a series capacitive circuit will cause the current to (increase)(decrease).

6. The change in circuit current was produced by a change in

______ a. Voltage.

______ b. Resistance.

______ c. Frequency.

______ d. Capacitive reactance.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

MODULE SELF-CHECK

1. Indicate which of the following are true (T) or false (F) concerning the physical characteristics of capacitors.

______ a. Ceramic capacitors, for the same values, are larger than air dielectric capacitors.

______ b. Two conductors separated by space form a capacitor.

______ c. A mica trimmer capacitor varies capacitance by varying plate area.

______ d. An air type variable capacitor varies capacitance by varying dielectric thickness.

______ e. A paper capacitor uses foil plates and a paper dielectric.

______ f. Electrolytic capacitors are normally polarized.

2. Indicate which of the following are true (T) or false (F) concerning the electrical characteristics of capacitors.

______ a. Capacitive reactance opposes a change in current.

______ b. Electrostatic lines of force go from the negative plate to the positive plate.

______ c. The force between two charged bodies increases as the distance between them increases.

______ d. The amount of charge stored in a capacitor is directly proportional to the applied voltage and capacitance.

______ e. A farad is the unit of measure of capacitance.

______ f. Capacitance is inversely proportional to dielectric thickness.

______ g. A charged capacitor offers infinite opposition to alternating current.

______ h. Capacitors are rated according to the amount of voltage the dielectric will withstand without breakdown.

______ i. A capacitor marked 600 V DC can take 450 V AC without damage.

______ j. Total capacitance of two capacitors in series is greater than either capacitance alone.

______ k. Capacitors connected in parallel will increase total capacitance.

______ l. Capacitive reactance is the opposition a capacitor offers to alternating current.

______ m. Capacitive reactance is usually expressed in microfarads.

3. In a capacitor, current and voltage are

______ a. 180° out-of-phase with current leading voltage.

______ b. 90° out-of-phase with current leading voltage.

______ c. 90° out-of-phase with voltage leading current.

______ d. 180° out-of-phase with voltage leading current.

4. Increasing capacitance will cause capacitive reactance to

______ a. increase.

______ b. decrease.

5. Increasing frequency will cause capacitive reactance to

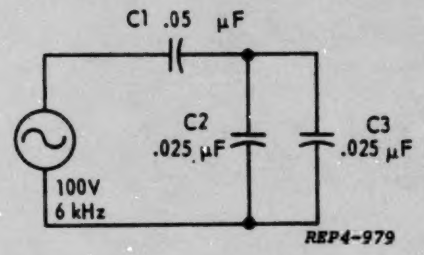
______ a. increase.

______ b. decrease.

6. Solve for the following using the circuit values shown.

C_t = ______________

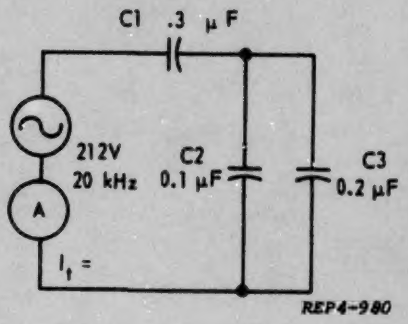
X_{C_t} = ______________



7. Solve for the following using the circuit values shown.

C_t = ______________

X_{C_t} = ______________



CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDANCE PACKAGE.

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Prepared by Keesler TTC
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Technical Training

Electronic Principles (Modular Self-Paced)

Module 13

MAGNETISM

October 1975

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October 1975

MAGNETISM

MODULE 13

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

TITLE	PAGE
Overview	1
List of Resources	1
Adjunct Guide	1
Module Self-Check	3
Answers	6

OVERVIEW

1. SCOPE: This module will explain the characteristics and terms of magnetism as they relate to the study of electronics.

2. OBJECTIVE: Upon completion of this module you should be able to satisfy the following objective:

a. Given a list of statements about magnetism, select the one which describes

(1) poles.
(2) magnetic field.
(3) flux density.
(4) permanent magnet.
(5) retentivity.
(6) permeability.
(7) reluctance.
(8) electromagnet.
(9) magnetic induction.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:
- Digest
- Adjunct Guide with Student Text, Vol II

AUDIO-VISUALS
- Television Lesson, Magnetism, TVK 30-165
- Audio Tape, Magnetism, NIK 0207 ABC
- Audio Tape, Magnetic Fields, NIK 0208 ABC

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

Supersedes KEP-GP-13, dated 15 April 1975. Existing stock may be used.

ADJUNCT GUIDE

MAGNETISM

Instructions:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers in the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text, Volume II and read paragraphs 3-1 through 3-19. Return to this page and answer the following questions.

1. Indicate which of the following are true (T) or false (F).

_____ a. Magnetism, like electricity is very visible.

_____ b. Magnetism has been known for centuries.

_____ c. Although we can see how magnetism works, we don't know the full details as to what causes it.

_____ d. Magnetism is defined as that property of a material that enables it to attract non-ferrous material.

_____ e. Some magnetic materials are iron, steel, nickel and cobalt.

_____ f. Magnets can be classified as natural or artificial.

_____ g. Natural magnets can be either temporary or permanent.

_____ h. The ability to retain magnetism is called retentivity.

_____ i. A material with low retentivity could be made into a permanent magnet.

_____ j. The concept of LINES OF FLUX is directly opposite of LINES OF FORCE.

_____ k. Magnetic lines of force leave the north pole and enter the south pole.

_____ l. Magnetic lines of force form a closed loop.

_____ m. Like poles will attract each other.

_____ n. Permeability is the ease with which magnetic lines of force are distributed throughout the core material.

_____ o. A compass is a practical use of the directional characteristics of a magnet.

_____ p. Iron filings can be used to show the pattern of magnetic lines of force.

_____ q. Magnetic lines of force are more concentrated in a region midway between the north and south poles on any magnet regardless of its shape.

2. Which of the following are NOT characteristics of magnetic lines of force?

_____ a. Continuous and always form closed loops.

_____ b. Can pass through all materials.

_____ c. Are able to cross one another.

_____ d. Tend to shorten themselves.

_____ e. Always enter or leave a magnetic material parallel to its surface.

3. Indicate which of the following are true (T) or false (F).

_____ a. One theory of magnetism is called the Domain Theory.

____ b. According to the Weber Theory, the molecular magnets will neutralize each other when they are aligned.

____ c. The Domain Theory is based on the electron spin.

____ d. A group of magnetic atoms is known as a domain.

____ e. Domains in any substance will never be magnetized to saturation.

____ f. The domains will line up when an external field is applied.

____ g. The stroking of an unmagnetized bar of iron by a magnet is called magnetic induction and will magnetize the bar.

____ h. If a bar magnet is broken in half the two new poles formed will repel each other.

CONFIRM YOUR ANSWERS

B. Turn to Student Text Volume II and read paragraphs 3-20 thru 3-36. Return to this page and answer the following questions.

1. Indicate which are true (T) and which are false (F) concerning electromagnetism.

____ a. It is capable of exerting mechanical force.

____ b. Some examples of present day use include the starter solenoid, and the door bell.

____ c. Wrapping a current carrying conductor around a soft iron bar will make an electromagnet.

____ d. A straight piece of wire carrying an electric current has a magnetic field around the wire.

____ e. The magnetic field can be reversed by reversing the direction of current flow.

____ f. The LEFT-HAND RULE can not be used to determine the direction of the magnetic field.

____ g. The strength of a magnetic field can not be increased by adding more loops or turns while keeping the current constant.

____ h. An electromagnet can be equivalent to a bar magnet.

____ i. The north pole can be found by using the LEFT-HAND THUMB RULE.

____ j. The strength of the magnetic field can be increased by increasing the current.

____ k. The number of magnetic lines (flux density) can be found directly by multiplying the current in amperes by the number of turns.

2. Consider two electromagnets using identical cores. Coil A has 100 turns and a current of 1 ampere flowing thru it. Coil B has only 10 turns and 10 amperes of current. Pick the correct statement concerning these two electromagnets.

____ a. Coil A has the stronger magnetizing force.

____ b. Coil B has the stronger magnetizing force

____ c. Both fields are equal.

____ d. Unable to determine.

3. Which of the following best describes magnetic saturation?

____ a. As current increases the number of lines increases.

____ b. As current increases the number of lines decreases.

______ c. As current increases the number of lines no longer increases.

4. Indicate which of the following are true (T) or false (F).

______ a. The magnetic field of an electromagnet is concentrated in the interior of the coil.

______ b. Flux density is the total number of magnetic lines inside a coil.

______ c. The number of magnetic lines inside the coil depends on the type of core material used.

______ d. A core material with a high permeability will have less lines than one with low permeability.

______ e. Flux density is directly proportional to the current and to the permeability of the core.

CONFIRM YOUR ANSWERS

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

MAGNETISM

QUESTIONS:

1. Indicate which of the following are true (T) or false (F).

______ a. Magnetism, like electricity, is a force which we can all see.

______ b. We really don't know what causes magnetism.

______ c. Magnetism is a property of certain materials to attract ferrous materials.

______ d. Iron, steel, nickel, cobalt and copper are magnetic materials.

______ e. Natural magnets are in more common usage than artificial magnets.

______ f. Magnetic lines of force never cross each other.

______ g. Magnetic lines of force leave the north pole.

______ h. Magnetic lines of force make closed loops.

______ i. Like poles attract each other.

______ j. Magnetic lines leave a magnet at right angles to the surface.

______ k. Reluctance is the opposition of a material to pass magnetic lines of force.

______ l. A soft iron bar has a greater reluctance than air.

______ m. Two types of magnets are natural and artificial.

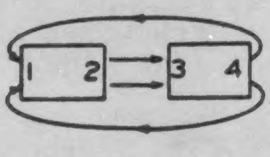
2. In the figure below, the polarities of the magnet ends are:

______ a. 2 and 3 north.

______ b. 1 and 4 north.

______ c. 1 and 3 south.

______ d. 2 and 4 opposite.



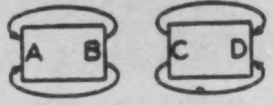
3. In the diagram shown, the north poles are:

______ a. A and D.

______ b. B and C.

______ c. C and A.

______ d. D and B.



4. What term is used to describe the ease with which magnetic lines of force will pass through a material?

_____ a. Permeability.

_____ b. Retentivity.

_____ c. Reluctance.

_____ d. Force.

5. A permanent magnet is a magnet that:

_____ a. Retains its reluctance.

_____ b. Loses its retentivity.

_____ c. Retains its magnetism.

_____ d. Loses its permeability.

6. Residual magnetism is defined as:

_____ a. The ease of flux flow in a permanent magnet.

_____ b. The opposition offered to magnetic lines of force.

_____ c. A small amount of magnetism remaining after the magnetizing force has been removed from a permanent magnet.

_____ d. Magnetism that remains in a substance after the magnetizing force has been removed.

7. What are the basic laws of magnetism?

_____ a. Like poles repel - unlike poles attract.

_____ b. Like poles attract - unlike poles repel.

8. Parallel magnetic lines of force traveling in the same direction _____ one another.

_____ a. Cross.

_____ b. Repel.

_____ c. Attract.

_____ d. Unite with.

9. What theory of magnetism assumes all magnetic substances are composed of small molecular magnets?

_____ a. Coulomb's Theory.

_____ b. Weber's Theory.

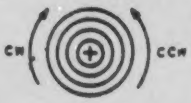
_____ c. The Domain Theory.

_____ d. Edison's Theory.

10. In the figure shown the direction of magnetic lines of force surrounding the conductor is:

_____ a. Clockwise (CW).

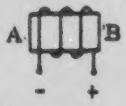
_____ b. Counterclockwise (CCW).



11. In the figure the north pole of the coil is

_____ a. A

_____ b. B



12. The product of the number of turns in a coil times the amperes is called:

_____ a. Ampere-turns.

_____ b. Turns ratio.

_____ c. Ampere capacity.

_____ d. Saturation.

13. Indicate which of the following are true (T) or false (F).

_____ a. Flux density is the number of magnetic lines per unit area.

_____ b. An air core will have a higher flux density than soft iron for the same current, turns and area.

_____ c. Increasing the number of turns with the same current will increase the flux density.

_____ d. A magnetic field will surround any current carrying conductor.

_____ e. An electromagnet consists of a current carrying conductor wrapped around soft iron.

_____ f. In the left-hand thumb rule the thumb will point to the south pole if the fingers point in the direction of current flow.

_____ g. The strength of an electromagnet is increased as current is increased.

_____ h. Magnetic saturation is reached when an increase in current will no longer cause an increase in the number of magnetic lines.

_____ i. An electromagnet of 12 turns passing .5A is stronger than one of only one turn and passing 10A.

_____ j. The magnetic field is most intense inside a coil.

_____ k. Rubbing a magnet over a non-magnetized iron bar will magnetize the bar by induction.

_____ l. Changing the polarity of DC to an electromagnet will not change the location of its north pole.

CONFIRM YOUR ANSWERS

ANSWERS TO A - ADJUNCT GUIDE

1. a. F g. F m. F
   b. T h. T n. T
   c. T i. F o. T
   d. F j. F p. T
   e. T k. T q. F
   f. T l. T

2. c and e

3. a. T d. T g. T
   b. F e. F h. F
   c. T f. T

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. a. T e. T i. T
   b. T f. F j. T
   c. T g. F k. F
   d. T h. T

2. c

3. c

4. a. T c. T e. T
   b. F d. F

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a. F h. T
   b. T i. F
   c. T j. T
   d. F k. T
   e. F l. F
   f. T m. T
   g. T

2. c

3. b

4. a

5. c

6. d

7. a

8. b

9. b

10. b

11. b

12. a

13. a. T g. T
    b. F h. T
    c. T i. F
    d. T j. T
    e. T k. T
    f. F l. F

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-14

Technical Training

Electronic Principles (Modular Self-Paced)

Module 14

INDUCTORS AND INDUCTIVE REACTANCE

November 1975

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

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Radar Principles Branch
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ATC GP 3AQR3X020-X
KEP-GP-14
November 1975

MODULE 14

INDUCTORS AND INDUCTIVE REACTANCE

This Guidance Package (GP) is designed to guide you through this module of the Electronic Principles Course. It contains a specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

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Overview	i
List of Resources	i
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Laboratory Exercise 15-1	4
Module Self-Check	6
Answers	8

OVERVIEW

1. SCOPE: This module will define inductance and show the construction of inductors, and explain their characteristics in electronic circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a group of statements, select the ones which describe the physical characteristics of an inductor.

b. From a group of statements, select the ones which describe the electrical characteristics of an inductor.

c. From a group of statements, select the one which describes the phase relationship of current and voltage in an inductor.

d. Given a list of statements, select the ones which describe the effect of varying frequency and inductance on inductive reactance.

e. Given the signal frequency, formulas, and the value of three inductors in a series-parallel configuration, compute the total inductance and the total inductive reactance.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text II

AUDIO VISUALS:

TVK-30-205, Inductance
TVK-30-253, Inductance and Inductive Reactance

LABORATORY EXERCISE:

Inductors and Inductive Reactance, 14-1

If, through training or experience, you are familiar with this subject matter, take the Module Self-Check. If not, select one of the resources and begin your study.

Supersedes KEP-GP-14, 1 May 1975. Previous editions will be used until stock is exhausted.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers in the back of this guidance package.

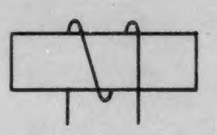
If you experience any difficulty, contact your instructor.

Begin the program.

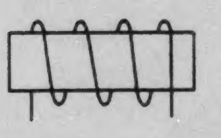
A. Turn to student text, volume II, and read paragraphs 3-37 through 3-48. Return to this page and answer the following questions.

1. Select the coil that would have the greatest amount of inductance.

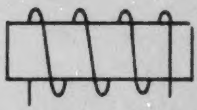
a. (1)



(2)



b. (1)



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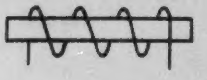
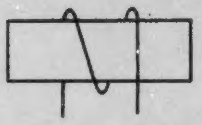
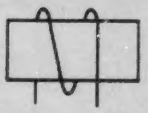


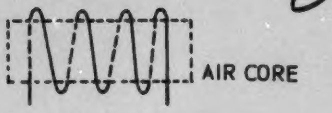
c. (1)



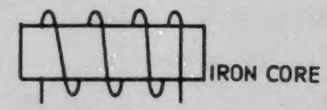
(2)



d. (1)



(2)



REP4-995

2. An electrical characteristic of an inductor is that an inductor opposes a ______________________ due to counter EMF.

3. The requirements for an induced voltage are:

a. ______________________

b. ______________________

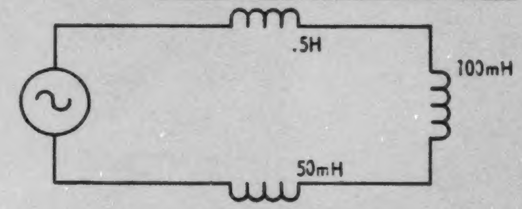
c. ______________________

CONFIRM YOUR ANSWERS.

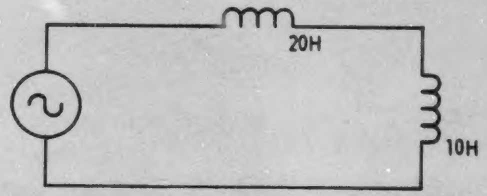
B. Turn to student text, volume II, and read paragraphs 3-49 through 3-54. Return to this page and answer the following questions.

1. Compute the total inductance in the following series circuits using $L_t = L_1 + L_2 + L_3 + \ldots$

a. L_t = ______________________



b. L_t = ______________________

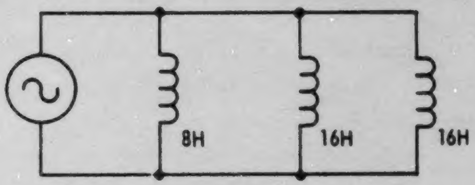


REP4-996

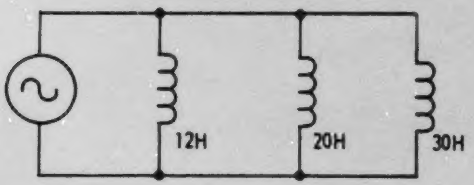
2. Compute the total inductance in the following parallel circuits using

$$L_t = \frac{1}{\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}+\cdots}$$

a. L_t = ______________________



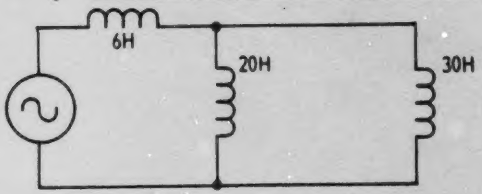
b. L_t = ______________________



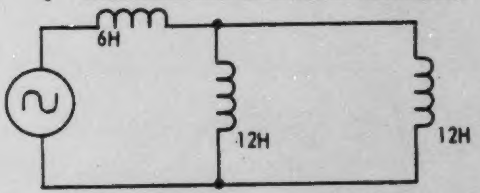
REP4-997

3. Compute the total inductance in the following series-parallel circuits.

a. L_t = ______________________



b. L_t = ______________________



CONFIRM YOUR ANSWERS.

C. Turn to student text, volume II, and read paragraphs 3-55 through 3-70. Return to this page and answer the following questions.

1. Finish the statements.

a. The symbol for inductive reactance is ______________________.

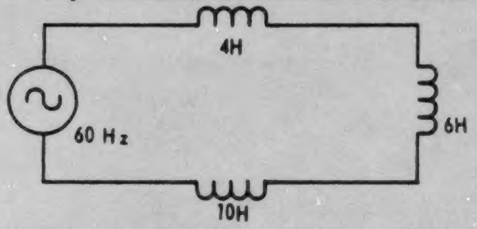
b. The unit of measure of inductive reactance is ______________________.

c. The two variables which affect inductive reactance are ______________ and ______________________.

2. The formula for inductive reactance is $X_L = 6.28fL$. Solve for inductance and inductive reactance in each circuit below.

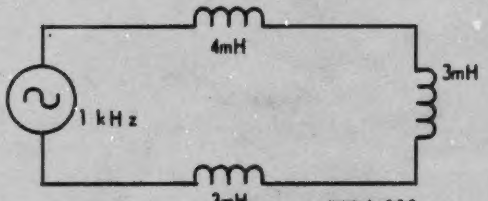
a. L_t = ______________________

X_{L_t} = ______________________



b. L_t = ______________________

X_{L_t} = ______________________



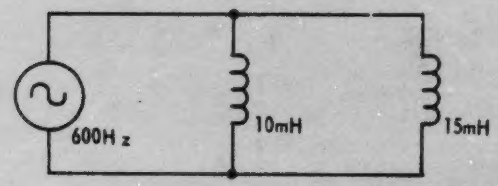
REP4-999

3. Compute the total inductance and the total inductive reactance for each circuit below:

$$L_t = \frac{1}{\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}+\cdots}$$

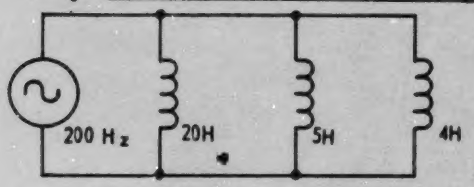
a. L_t = ______________________

X_{L_t} = ______________________



b. L_t = ______________________

X_{L_t} = ______________________

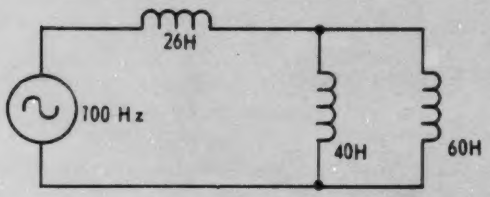


REP4-1000

4. Compute the total inductance and the total inductive reactance for each circuit below.

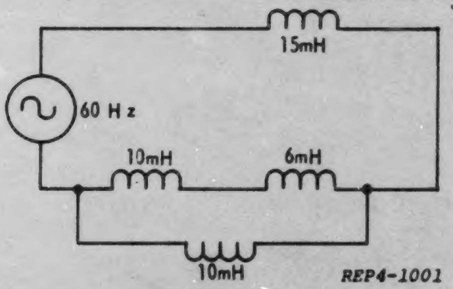
a. L_t = ______________________

X_{L_t} = ______________________



b. L_t = ______________________

X_{L_t} = ______________________

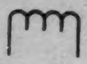


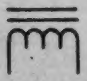
REP4-1001

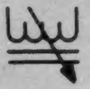
CONFIRM YOUR ANSWERS.

D. Turn to student text, volume II, and read paragraphs 3-71 through 3-83. Return to this page and answer the following questions.

1. Select the description which identifies the type of core the inductors have.

a.  ______________________

b.  ______________________

c.  ______________________

REP4-1002

(1) Fixed magnetic core.
(2) Air core.
(3) Variable magnetic core.

2. For each type of inductor loss, listed below, state how it can be reduced.

a. Copper loss: ______________________

____

b. Hysteresis loss: ______________________

____

c. Eddy currents: ______________________

____

3. Give the physical characteristics of each type of inductor listed below.

a. Power:

(1) Core type -

____

(2) Physical size -

____

(3) Wire size -

____

b. Audio:

(1) Core type -

(2) Physical size -

(3) Wire size -

(4) Winding style -

c. RF:

(1) Ccore style -

(2) Physical size -

(3) Wire turns -

(4) Winding style -

CONFIRM YOUR ANSWERS.

LABORATORY EXERCISE 14-1

OBJECTIVES:

1. Determine what effect a change in voltage has on an inductive circuit.

2. Determine what effect a change in frequency has on an inductive circuit.

3. Determine what effect a change in inductance has on an inductive circuit.

EQUIPMENT:

1. AC Inductor and Capacitive Trainer, 5967
2. Sine Square-Wave Generator, 4864
3. Meter Panel (0-10, 50, 250 AC mA), 4568
4. AN/PSM-6

REFERENCES:

1. Student text, volume II, paragraphs 3-49 through 3-71.

2. Test Equipment Operating Instructions book.

CAUTION: OBSERVE BOTH PERSONNEL AND EQUIPMENT SAFETY RULES AT ALL TIMES. REMOVE WATCHES AND RINGS.

PROCEDURES:

A. Preparation of the trainer and test equipment.

1. PSM-6:

a. FUNCTION switch - ACV-1 k ohm/V

b. RANGE switch - 50 V

2. AC inductor and capacitive trainer placed on T bench before you.

3. Sine Wave Generator:

a. Plug into 110-volt source.

b. SQUARE WAVE AMPLITUDE - ON slightly clockwise (CW).

c. SINE WAVE AMPLITUDE control - 0 V (fully CCW).

d. SINE WAVE RANGE control - 10 V.

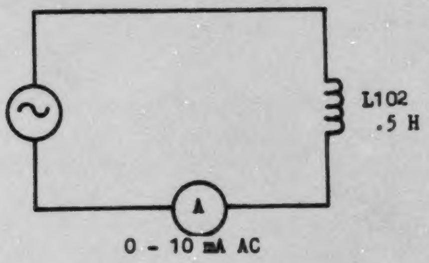
e. FREQ MULTIPLIER control - 10.

f. FREQUENCY (CPS) dial - 30.

B. Determine what effect a change in voltage has on an inductive circuit.

1. Connect the inductive circuit as shown in the figure below.

Sine wave generator set to 300 Hz.



2. Set the frequency of the sine wave generator to 300 (FREQ MULTIPLIER to 10 and FREQUENCY dial to 30). DO NOT TOUCH the frequency controls during the remainder of this objective.

3. Adjust the amplitude of the sine wave output to 5 V AC at the output terminals of the sine wave generator. Measure with the PSM-6.

4. Read ad record the circuit current.

Frequency at 300 Hz, E_a = 5 V

I_t = ______________________ mA.

5. Adjust the amplitude of the sine wave output to 10 V AC at the output terminals of the sine wave generator.

Frequency at 300 Hz, E_a = 10 V

I_t = ______________________ mA.

6. An increase in E_a in an inductive circuit will have what effect on circuit current?

____a. Remain the same.

____b. Increase.

____c. Decrease.

7. The current change was produced by a change in:

____a. Resistance.

____b. Inductance.

____c. Reactance.

____d. Voltage.

CONFIRM YOUR ANSWERS.

C. Determine what effect a change in frequency has on an inductive circuit.

1. Using the figure above, adjust the amplitude of the sine wave until the output is 10 V AC at the output terminals of the sine wave generator. NOTE: DO NOT TOUCH the amplitude control during the remainder of this objective.

2. Set the output of the sine wave generator of each of the frequencies listed and record the current.

FREQUENCY	CIRCUIT CURRENT
200 Hz	__________ mA
300 Hz	__________ mA
500 Hz	__________ mA

3. In a series inductive circuit an increase in frequency will (INCREASE) (DECREASE) circuit current.

4. In an inductive circuit the current change produced by a change in frequency is produced by a change in:

____a. Inductance.

____b. Resistance.

____c. Reactance.

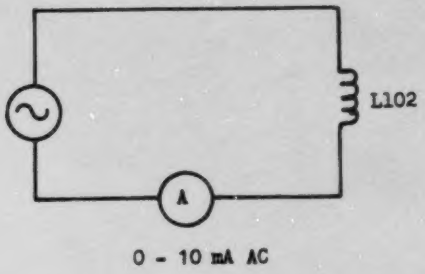
____d. Voltage.

CONFIRM YOUR ANSWERS.

D. Determine the effect of a change in the inductance in an inductive circuit.

1. Connect circuit as shown in the figure below.

Sine wave generator set to 100 Hz.



2. Set the frequency of the generator to 100 Hz.

3. Adjust sine wave amplitude until the ammeter indicates 4 mA. DO NOT CHANGE the FREQUENCY or AMPLITUDE controls during the remainder of this objective.

4. Replace L102 with L101 and record circuit current.

________________ mA.

5. Replace L101 with L103 and record circuit current.

________________ mA.

6. An increase in inductance in a series inductive circuit will cause the current to (INCREASE) (DECREASE).

7. The change in circuit current was produced by a change in:

____ a. Voltage.

____ b. Frequency.

____ c. Resistance.

____ d. Inductive reactance.

CONFIRM YOUR ANSWERS.

MODULE SELF-CHECK

Questions:

1. What are four physical factors which determine the inductance of a coil?

a. ________________

____

b. ________________

____

c. ________________

____

d. ________________

____

2. List the changes that must be made in each of the factors to increase the inductance of a coil.

a. ________________

____

b. ________________

____

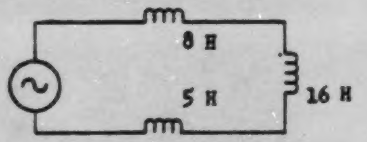
c. ________________

____

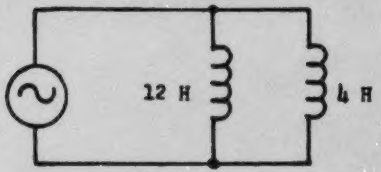
d. ________________

____

3. Calculate the total inductance of the circuit below. ________________



4. Compute the total inductance of the following circuit. ____________



5. Indicate if the following are true (T) or false (F).

_____ a. Inductance is defined as the opposition to AC.

_____ b. The symbol for inductance is L.

_____ c. Counter EMF is an opposing induced voltage caused for self-inductance.

_____ d. A magnetic field, a conductor, and current flow in one direction are required to induce voltage.

_____ e. An increasing current causes an expanding magnetic field.

_____ f. Close spacing decreases the flux linkage.

_____ g. The unit of inductance is the henry and the symbol is H.

_____ h. Inductors in series add.

_____ i. Inductive reactance is the opposition to AC by a coil.

_____ j. The symbol for inductive reactance is X_L.

_____ k. Frequency applied to an inductor will affect X_L.

_____ l. If inductance increases, X_L will also increase.

_____ m. An inductor dissipates power.

_____ n. The permeability of the core material does not affect the inductive reactance.

_____ o. Voltage leads current by 90° in an inductor.

6. Find X_L when a 20 kHz signal is applied to a 3 mH coil.

_____ a. 37.68 ohms.
_____ b. 376.8 ohms.
_____ c. 37 k ohms.
_____ d. 3.768 k ohms.

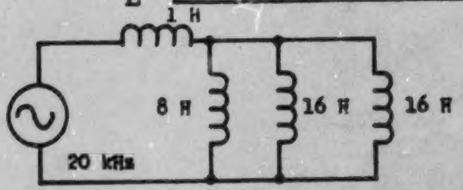
7. Find X_L when a 400 Hz signal is applied to an 8 H coil.

_____ a. 200 ohms.
_____ b. 2 k ohms.
_____ c. 20 k ohms.
_____ d. 200.96 k ohms.

8. With the values given find:

a. Total inductance = ____________

b. Total X_L = ____________



9. Find total X_L for the circuit of question number 8 when the frequency is changed to 200 kHz.

X_L = ____________

10. Three inductor losses are:

a. ____________

b. ____________

c. ____________

11. Three types of inductors are:

a. ____________

b. ____________

c. ____________

CONFIRM YOUR ANSWERS.

ANSWERS TO A ADJUNCT GUIDE

1a. (2) b. (1) c. (2) d. (2)
2. Change in current flow.
3. A magnetic field, a conductor, and relative motion.

If you missed ANY questions, review the material before you continue.

ANSWERS TO B ADJUNCT GUIDE

1a. .65 H b. 30 H
2a. 4 H b. 6H
3a. 18 H b. 12 H

If you missed ANY questions, review the material before you continue.

ANSWERS TO C ADJUNCT GUIDE

1a. X_L b. Ohm
c. Frequency and Inductance
2a. 20 H and 7536 ohms
b. 10 mH and 62.8 ohms
3a. 6 mH and 22.6 ohms
b. 2 H and 2512 ohms
4a. 50 H and 31.4 k ohms
b. 21 mH and 7.9 ohms

If you missed ANY questions, review the material before you continue.

ANSWERS TO D ADJUNCT GUIDE

1a. (2) b. (1) c. (3)
2a. By increasing the conductor size
b. By using high permeability material for the core.
c. By laminating the core.

2a(1) Laminated iron (2) Medium to large
(3) Large
b(1) Laminated iron (2) Small to medium
(3) Small (4) Special winding techniques
c(1) Air or powdered iron (2) Small
(3) Few (4) Special winding styles

If you missed ANY questions, review the material before you continue.

ANSWERS TO B LAB EX 14-1

4. $I_t = 1.4$ mA (approximately)

5. $I_t = 2.8$ mA (approximately)

6. b - Increase ($I_t = E_a/X_L$)

7. d

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO C LAB EX 14-1

2. 2.5 mA (approximately)
2.0 mA (approximately)
1.5 mA (approximately)

3. Decrease

4. c

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO D, LAB EX 14-1

4. 4.3 mA (approximately)

5. 0.9 mA (approximately)

6. Decrease

7. d

If you missed ANY questions, ask your instructor for assistance.

ANSWERS TO MODULE SELF-CHECK

1a. Number of turns
b. Length of coil
c. Diameter of core (cross sectional area)
d. Type of core material

2a. Increase number of turns.
b. Decrease length
c. Increase core dameter
d. Use a core of a higher permeability

3. 29 H

4. 3 H

ANSWERS TO MODULE SELF-CHECK

5a. F b. T c. T d. F e. T f. F
g. T h. T i. T j. T l. T m. F
n. F 0. T

6. b

7. c

8a. 5 H b. 628 k ohms

9. 6.28 M ohms

10a. Copper b. Hysteresis
c. Eddy current

11a. Power b. Audio c. RF

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-15

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 15

TRANSFORMERS

1 June 1974

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

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Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-15
1 June 1974

ELECTRONIC PRINCIPLES

MODULE 15

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

TITLE	PAGE
Overview	1
List of Resources	2
Digest	3
Adjunct Guide	5
Module Self Check	11

Supersedes KEP-GP-15, 1 November 1973. Use existing stock until exhausted.

TRANSFORMERS

1. SCOPE: This module will explain transformer action and show its construction and explains its characteristics and function in electronic circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

   a. Given a schematic diagram of a transformer with a resistive load, turns ratio, primary input voltage, and formulas, determine the

      (1) output voltage.

      (2) reflected impedance.

      (3) phase relationships between secondary and primary voltages.

   b. From their schematic representation, identify air core, iron core, auto, and multiple winding transformers.

   c. From a list of statements, select the procedures for checking open and shorted transformers.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK. IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

TRANSFORMERS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest

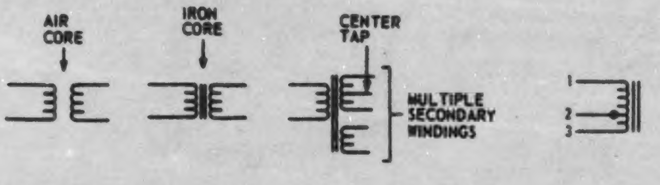
Adjunct Guide with Student Text

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

TRANSFORMERS

A transformer is a device that transfers electrical energy from one circuit to another by electromagnetic induction.

Transformer schematic symbols are drawn in reference to the construction.



Air-core transformers are commonly used in circuits carrying radio-frequency energy.

Iron-core transformers are commonly used in audio and power circuits.

Multiple secondary winding types are commonly used in power supply circuits.

Auto-transformers are used where we do not need the electrical isolation of separately insulated primary and secondary windings.

A transformer can be connected to step-up or step-down voltage. The turns ratio of the primary to secondary will determine its use in the circuit.

The behavior of ideal transformers can be calculated from the following set of basic equations:

Voltage-Turns relationship $\frac{E_p}{E_s} = \frac{N_p}{N_s}$

Voltage-Current relationship $\frac{E_p}{E_s} = \frac{I_s}{I_p}$

Current-Turns relationship $\frac{N_p}{N_s} = \frac{I_s}{I_p}$

Impedance-Turns relationship $\frac{Z_p}{Z_s} = \frac{(N_p)^2}{(N_s)^2}$

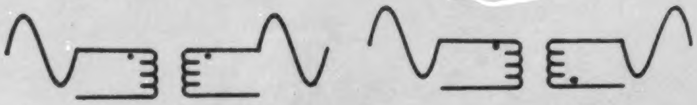
Impedance-Voltage relationship $\frac{Z_p}{Z_s} = \frac{(E_p)^2}{(E_s)^2}$

Impedance-Current relationship $\frac{Z_p}{Z_s} = \frac{(I_s)^2}{(I_p)^2}$

Conservation of Energy relationship $P_{pri} = P_{sec}$

DIGEST

From the schematic representation you can determine the phase relationship between secondary and primary voltage. The sense dots in the schematic indicate the ends of the windings which have the same polarity at the same instant of time.



The phase of the output voltage can be reversed by reversing the direction of one of the windings, or simply by reversing the leads to one of the windings. Where it is necessary to keep track of the phase relationship in a circuit, we mark one end of each winding with a sense dot.

An ohmmeter can be used to determine whether a transformer is open or shorted by comparing the resistance of the windings to a known specification. The best way to check a transformer is to apply the rated input voltage and compare the measured output voltage to its specification.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

TRANSFORMERS

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

ADJUNCT GUIDE

A. Turn to Student Text, Volume II, and read paragraphs 4-1 through 4-12. Return to this page and answer the following questions.

1. Three requirements for electromagnetic induction are:

   a. ______________________________

   b. ______________________________

   c. ______________________________

2. Define:

   a. **Self-induction:**

   ____

   b. **Mutual induction:**

   ____

   c. **The unit of measurement of inductance, the Henry:**

   ____

   d. **Flux linkage:**

   ____

3. a. A transformer is a device that transfers electrical energy from one circuit to another by

   ____

   b. The winding that is connected to the source is called the ______________ winding.

   c. The winding that supplies energy to the load is called the ______________ winding.

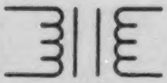
CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

◆ ◆ ◆

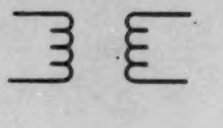
B. Turn to Student Text, Volume II, and read paragraphs 4-13 through 4-30. Return to this page and answer the following questions.

1. Identify each transformer schematic representation as to air core, iron core, auto, or multiple winding.

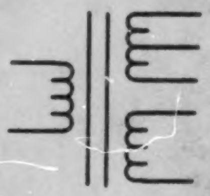
   a. ______________________________



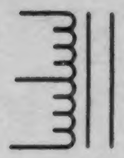
b. ________________________________



c. ________________________________



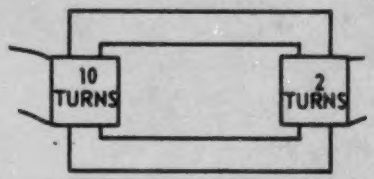
d. ________________________________



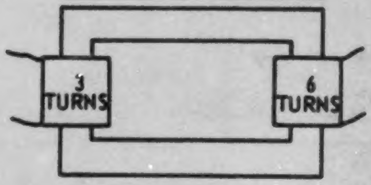
REP4-1006

2. Determine the turns ratio of each transformer pictorial diagram.

a. ________________________________



b. ________________________________

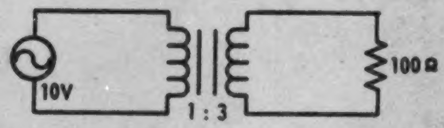


REP4-1007

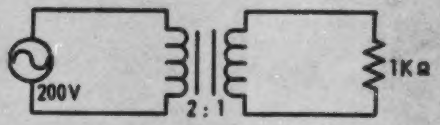
3. Given a schematic diagram of a transformer with a resistive load, turns ratio, primary input voltage, and formulas, determine the output voltage.

$$E_s = \frac{N_s E_p}{N_p}$$

a. $E_s =$ ________________________________



b. $E_s =$ ________________________________



ANSWERS TO A.

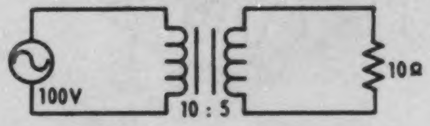
1. a. A magnetic field.
   b. A conductor.
   c. Relative motion between the field and conductor.
2. a. Self-induction is the process by which the magnetic field of a conductor induces a CEMF in the conductor itself.
   b. Mutual induction is the action of inducing a voltage in one circuit by varying the current in some other circuit.
   c. A Henry is the inductance in a circuit which induces an EMF of one volt when the current is changing at a rate of one ampere per second.
   d. Flux linkage is the interlocking of magnetic lines of force; it is those magnetic lines around one coil or wire which link another coil, or wire.
3. a. electromagnetic induction
   b. primary
   c. secondary

If you missed ANY questions, review the material before you continue.

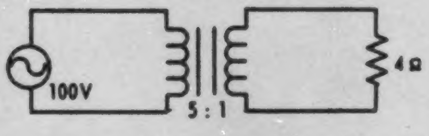
4. Given a schematic diagram of a transformer with a resistive load, turns ratio, primary input voltage, and formulas, determine the reflected impedance.

$$Z_p = Z_s \left(\frac{N_p}{N_s}\right)^2$$

a. Z_p = ______________________



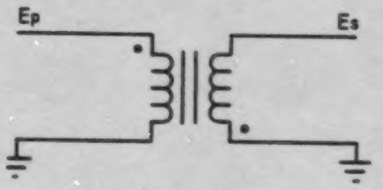
b. Z_p = ______________________



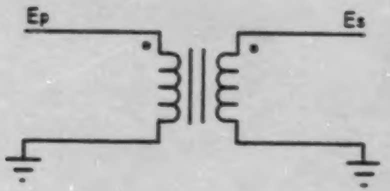
REP4-1008

5. Determine the phase relationship between secondary (E_s) and primary (E_p) voltages for each transformer.

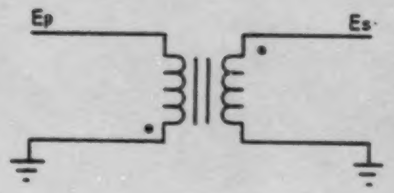
a. ______________________ phase



b. ______________________ phase



c. ______________________ phase



REP4-1009

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

◆ ◆ ◆

C. Turn to Student Text, Volume II, and read paragraphs 4-31 through 4-35. Return to this page and answer the following questions.

1. When troubleshooting a transformer with an ohmmeter, a secondary resistance reading of $\infty \Omega$ would indicate a/an (open) (shorted) secondary.

2. If the rated input voltage is applied to the primary of a step-down transformer and a measurement of the secondary is low, you would assume that the secondary has (open) (shorted) winding.

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

◆ ◆ ◆

ANSWERS TO B:

1. a. Iron Core
   b. Air Core
   c. Multiple winding - Iron Core
   d. Auto transformer - Iron Core
2. a. 5:1
   b. 1:2
3. a. 30 V
   b. 100 V
4. a. 40 Ω
   b. 100 Ω
5. a. 180 degrees out of phase
   b. in-phase
   c. 180 degrees out of phase

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. open
2. shorted

If you missed any questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

TRANSFORMERS

QUESTIONS:

1. Indicate which of following are true (T) or false (F).

___ a. Two types of electromagnetic induction are self and mutual.

___ b. Mutual induction has to do with transformer action.

___ c. The symbol for mutual induction is "mu."

___ d. The symbol for self induction is "L."

___ e. A transformer will transfer electrical energy from one part of a circuit to another by direct means.

___ f. Transformers must use a changing current source.

___ g. A transformer will have at least two windings called a primary and a secondary.

___ h. More than one secondary may be used.

___ i. Air, iron, copper, and aluminum are types of core material which can be used for audio and power transformers.

___ j. Laminated iron is used as a core for RF transformers to eliminate hysteresis losses.

___ k. Laminations are insulated one from the other.

___ l. When 100% of the primary flux lines cut the entire secondary winding, the coefficient of coupling is one.

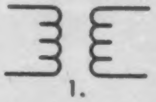
2. Match the following figures with the proper name.

a. Multiple winding ______________

b. RF ______________

c. Autotransformer ______________

d. Audio ______________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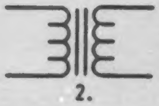
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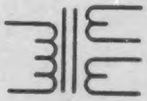
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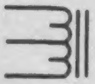
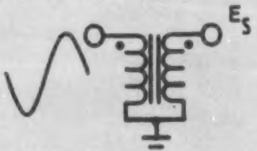

4.

REP4-1010

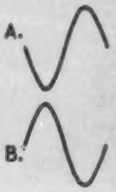
3. Indicate which waveshape is correct for E_s when the input is as shown.

___ a.

___ b.



REP4-1011



MODULE SELF-CHECK

4. A transformer with 1,800 turns in the primary and 100 V AC applied will have ________ volts in the 18,000 turn secondary.

5. The transformer in question #4 is a

___ a. step-up.

___ b. step-down.

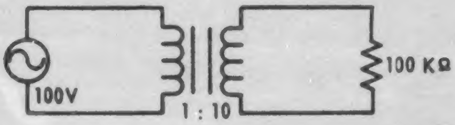
6. Find the reflected impedance in the circuit shown.

___ a. 10 Ω

___ b. 100 Ω

___ c. 1000 Ω

___ d. 10000 Ω



REP4-1012

7. Indicate which of following are true (T) or false (F) concerning transformers.

___ a. An ohmmeter can be used to check for opens and shorts.

___ b. A voltmeter can NOT be used for checking shorts, only opens.

___ c. A voltmeter may be used to determine if a transformer is step-up or step-down.

___ d. A step-down ratio would be indicated if the primary measured 58 ohms while the secondary is 4 kilohms.

___ e. Shorted secondary turns would be the trouble if the primary voltage was 120 V and the secondary was 4 V instead of the 5 V it should be.

___ f. The secondary resistance is higher than the primary resistance for a step-up transformer.

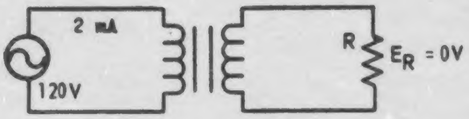
8. What is the trouble indicated in this circuit.

___ a. Open primary

___ b. Open secondary

___ c. Shorted primary

___ d. Open resistor (R).



REP4-1013

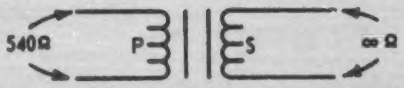
9. Indicate the possible trouble in this circuit.

____a. Open primary

____b. Shorted primary

____c. Open secondary

____d. Shorted secondary



REP4-1014

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK:

1. a. T
   b. T
   c. F
   d. T
   e. F
   f. T
   g. T
   h. T
   i. F
   j. F
   k. T
   l. T
2. a. 3
   b. 1
   c. 4
   d. 2
3. a
4. 1 kV
5. a
6. c
7. a. T
   b. F
   c. T
   d. F
   e. T
   f. T
8. b
9. c

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

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ATC 149

PREPARE THE MAN

ATC PT 3AQR3X020-X
Prepared by Keesler TTC
KEP-PT-15

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

Module 15

TRANSFORMERS

1 January 1975

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

ATC Keesler 6-1405

DO NOT USE ON THE JOB

Basic & Applied Electronics Department
Keesler AFB, Mississippi

PT 3AQR3X020-X
KEP-PT-15
1 January 1975

ELECTRONIC PRINCIPLES

MODULE 15

TRANSFORMERS

This illustrated Programmed Text is designed to aid in the study of Transformers. Each page contains an important idea or concept to be understood before proceeding to the next. An illustration for each objective is presented to clarify what is to be learned.

At the bottom of each page, there are a few questions to bring out the main points. These are indicated by.... It is hoped that these questions also aid in understanding the subject a little better.

Q-1 or Q-2 etc..

The answers to these questions will be found on the top of a following page, indicated as..... Short comments may follow the answers to help understand why a question may have been missed.

A-1 or A-2 etc..

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OBJECTIVES

Upon completion of this module, you should be able to satisfy the following objectives:

a. Given a schematic diagram of a transformer with a resistive load, turns ratio, primary input voltage, and formulas, determine the
   (1) output voltage.
   (2) reflected impedance.
   (3) phase relationships between secondary and primary voltages.

b. From their schematic representation, identify air core, iron core, auto, and multiple winding transformers.

c. From a list of statements, select the proceedures for checking open and shorted transformers.

Supersedes KEP-PT-15, 1 September 1974, previous edition obsolete.

INTRODUCTION

A small transistor radio contains 5 transformers, while a Radar system may contain 50. Giant distribution transformers make the transmission of AC electrical power possible, and sub-miniature transformers, operating at high frequencies, transfer radio signals between complex electronic circuits.

From high fidelity stereo equipment, to aircraft and missile flight control systems, the transformer performs a variety of simple and complicated tasks. It is reliable, and wastes little-or-no power while operating.

Television signals arrive at a transformer direct from the antenna, and at the same time another type is developing high voltages which the picture tube requires. And another is delivering sound signals to the speaker.

From its simple beginning, an entire industry has grown to meet the never-ending demand for new and higher quality transformers.

This is a study of the basic uses, types, operating principles, needs, calculations, and troubleshooting of transformers.

DEFINITION

A device used to transfer electrical power, at a higher or lower voltage level.

One of the advantages of AC over DC, is the ability to raise or lower the voltage levels of AC power, thru the use of electrical transformers. Raising or lowering DC voltages involves serious energy losses.

Q-1 a. A transformer is a device used to transfer electrical ___________.
b. Transformers raise or lower the ___________ level of AC power.
c. T-F AC power has no advantages over DC power.
d. T-F AC voltage can be raised thru the use of a transformer.
e. T-F AC power can be increased by using a transformer.

ELECTRICAL POWER

Electrical power is a combination of Voltage (E) and Current (I).

POWER = Voltage × Current

Many combinations of voltage and current can result in 1000 WATTS of Power.

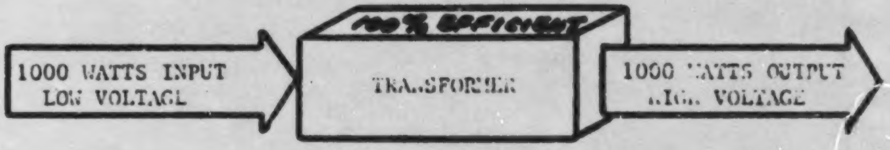
1000 WATTS = 500 VOLTS × 2 AMPERES

1000 WATTS = 200 VOLTS × 5 AMPERES

1000 WATTS = 10 VOLTS × 100 AMPERES

ELECTRICAL POWER TRANSFER

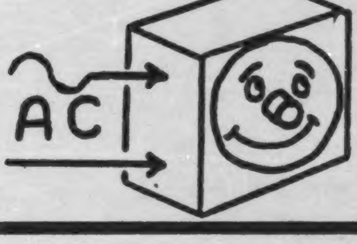
The transfer of electrical power thru a transformer is so efficient, that the small losses involved are normally ignored.

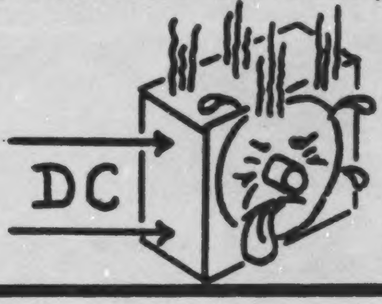


It is essential, for long distance electric power distribution, to have the Power at as high a voltage level as possible. This reduces the energy loss in the power transmission lines. The reasons will be discussed later.

AC AND DC TRANSFORMERS??

Only alternating current AC works in a transformer. To direct current DC, the transformer acts as a large wire-wound resistor, dissipating all the power in the form of heat.



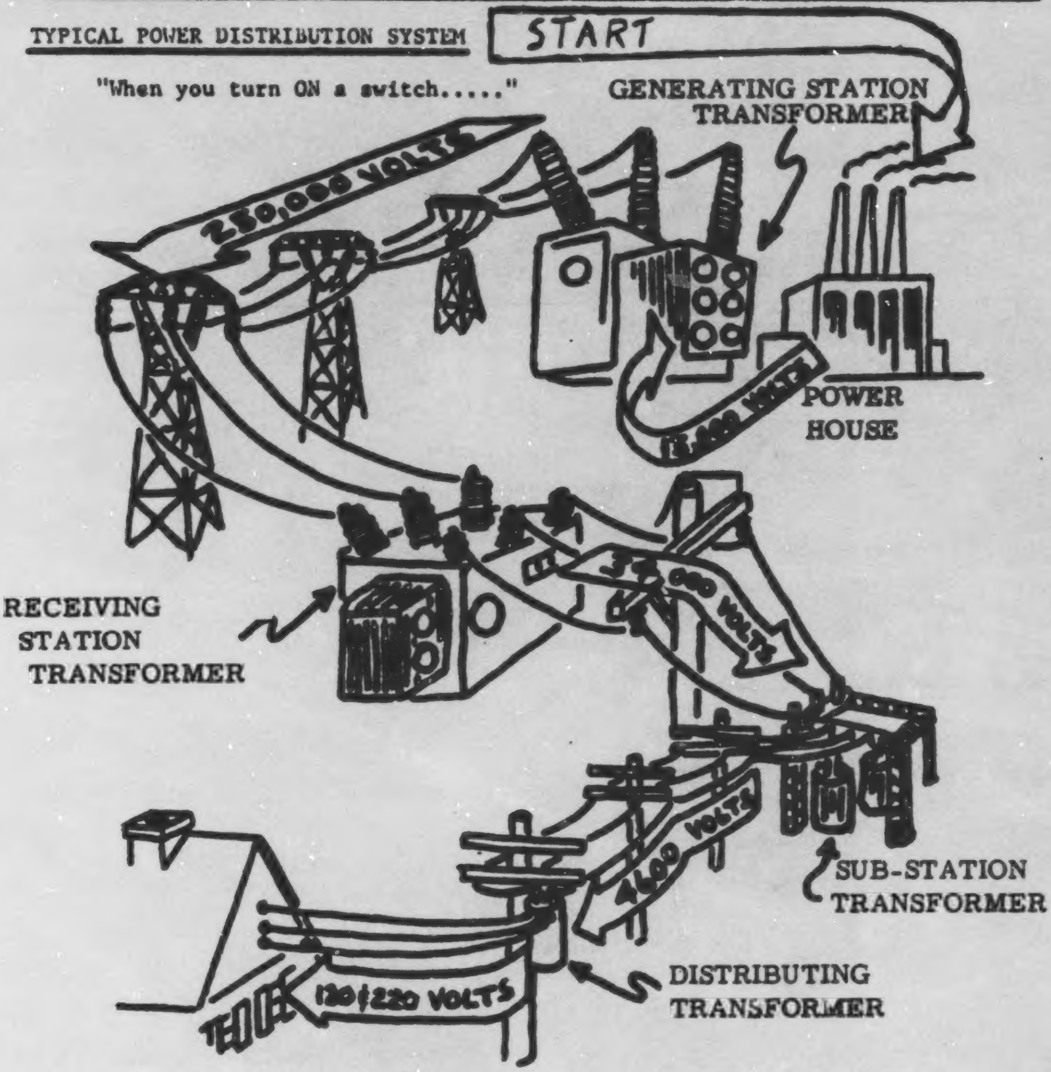


Q-2
a. Electrical power is a combination of __________ and __________.
b. T-F Transformers can be considered 100% efficient.
c. T-F Long distance power transmission requires transformers.
d. T-F Transformers work equally well with AC or DC power.

A-1	a. power	c. False	e. False....this would be getting something for nothing.
	b. voltage	d. True	

TYPICAL POWER DISTRIBUTION SYSTEM

"When you turn ON a switch....."



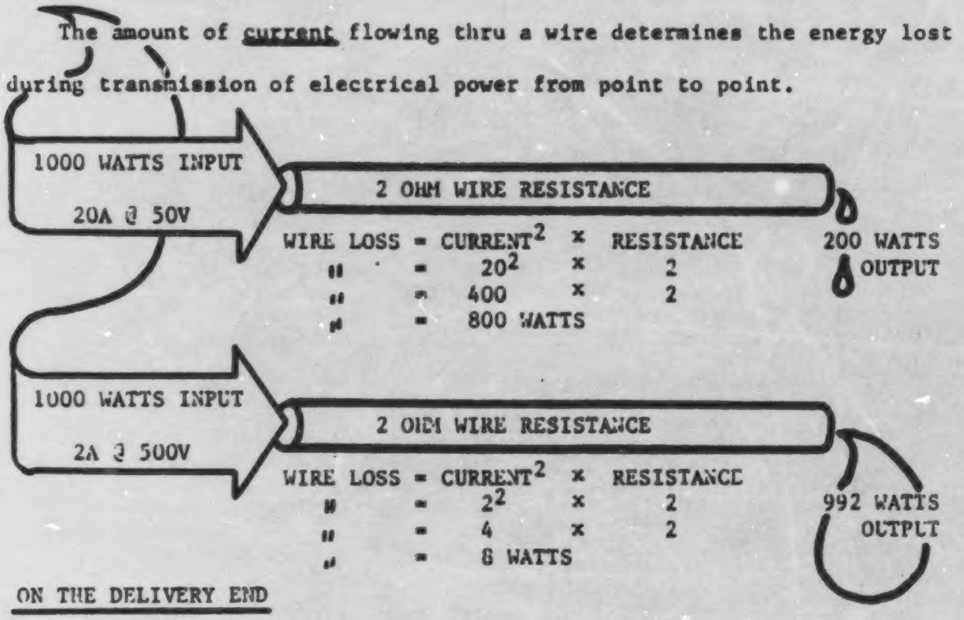
The importance of transformers can best be seen, when it is imagined what it would be like without electric power. The extremely high transmission voltages shown are absolutely necessary. Without them, most of the electric power in the system would be dissipated as heat. This is furthur explained in "POWER LINE LOSSES" which follows.

Q-3 a. T-F Electrical power passes thru several transformers, between the "power house" and the "using house".
b. T-F High transmission voltages are NOT necessary.

A-2
a. voltage and current
b. True
c. True...to reduce "line losses".
d. False...they work with AC only.

POWER LINE LOSSES

The amount of current flowing thru a wire determines the energy lost during transmission of electrical power from point to point.



ON THE DELIVERY END

By raising the voltage to extremely high levels, the amount of current required in the transmission of electrical power can be kept low, and the line losses held to a minimum.

It is not practical to produce electrical power at the very high transmission voltage levels required, due to "arcing and sparking" within the AC generator. Therefore, the output voltage of the generator is "stepped-up" thru the use of a transformer, for delivery along "high-tension lines".

ON THE RECEIVING END

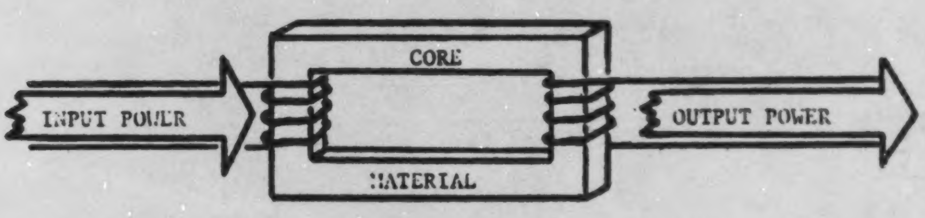
250,000 volts is not the best thing to have "running around the house", so the voltage level of the electrical power is "stepped-down" thru a series of transformers to the 120 volt and 220 volt levels required for residential uses.

Q-4
a. T-F The higher the voltage, the lower the loss.
b. Raising the voltage results in less ______________ flow.
c. T-F Some "line-loss" is always involved.

A-3 a. True....often passing thru 5 or more transformers.
b. False...they ARE necessary, and the-higher-the-better.

BASIC TRANSFORMER CONSTRUCTION

Although the differences among transformers are many, their fundamental construction has a striking similarity.....two or more coils of **INSULATED** wire, wound on some type of "core" material.



The particular physical construction of any transformer, is determined by the task to be performed. Sizes range from "Distribution Transformers", as large as a house, to the subminiature "Pulse Transformer", the size of a pea.

Imagine the physical differences which must exist in the following list of transformer types.....

⇨ No attempt should be made to "memorize" any part of this list.

Power Transformer
Plate Transformer
Filament Transformer
Audio Transformer
Input Transformer
Output Transformer
Interstage Transformer
Mixing Transformer
Matching Transformer
Driver Transformer
Pulse Transformer
Magnetic Amplifier
Saturable Transformer
Converter Transformer
Constant Voltage Tfmr
Discriminator Transformer
Blocking Oscillator Tfmr
Ultrasonic Transformer
Auto-Transformer
Isolation Transformer
Line Booster Tfmr
Variable Transformer
Toroidal Transformer
Chopper Transformer
Control Transformer
Rectifier Transformer
Radio Frequency Tfmr
Video Transformer
Phase Detector Tfmr
Balanced Modulator Tfmr
Single Phase Tfmr
Two Phase Transformer
Three Phase Tfmr
Bridge Transformer
Harmonic Transformer
Delta Transformer
Wye Transformer
Voltage Regulation Tfmr
Flyback Transformer
Vibrator Transformer
Vertical Output Tfmr
Push-Pull Transformer
Universal Transformer
Line Transformer
Modulation Transformer
Photoflash Transformer
Bias Transformer
Multi-Tapped Tfmr
Inverter Transformer
Intermediate Freq Tfmr
And on, and on, and on...

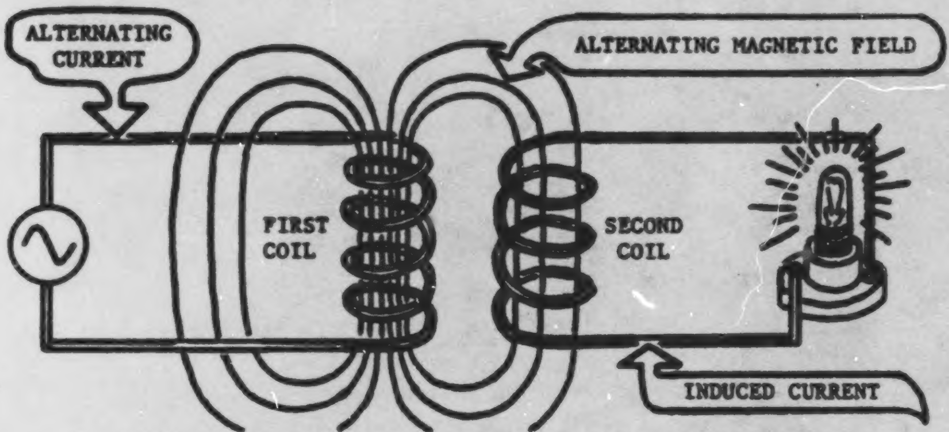
Q-5 a. Transformers are used to transfer electrical ____________.
b. T-F All transformers "step-up" the voltage.
c. T-F All transformers have two coils of wire.

A-4 a. True c. True...at least until wire with ZERO ohms of
b. current resistance becomes practical to produce.

TRANSFORMER ACTION

"Any conductor material, will have an electrical current generated within it, when exposed to a changing or alternating magnetic field". This is called the phenomenon of INDUCTION.

MUTUAL INDUCTION or "transformer action" occurs when alternating current in one coil of wire, creates an alternating magnetic field, which induces a current to flow in a second, nearby coil.



In this manner, useful electrical power is generated in the second coil. The two coils are not physically connected. They are magnetically coupled together.

A stronger and more concentrated magnetic field would be produced if both coils are wound on some type of magnetic core material.

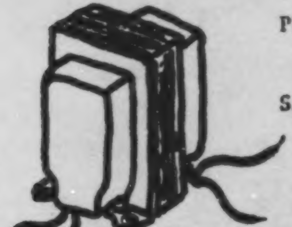
Direct current (DC) magnetic fields are stationary, and therefore would NOT induce any current into the second coil. Only alternating current (AC) can be transferred thru a transformer, due to its constantly changing and alternating magnetic field.

Q-6 a. T-F An alternating magnetic field will create an induced current in any nearby conductor material.
b. T-F DC will produce an alternating magnetic field.
c. The strength of the alternating magnetic field depends upon the number of turns, and the amount of ________________.

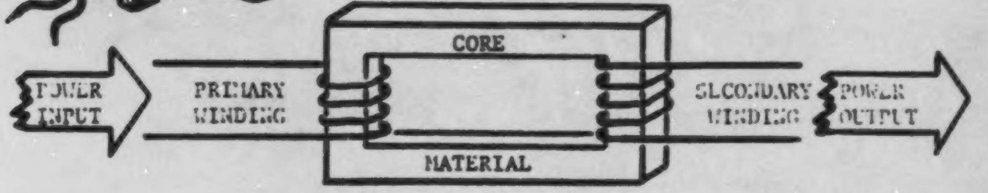
A-5 a. power c. False...some special types have only one.
b. False...some "step-down".

PRIMARY AND SECONDARY WINDINGS

Transformer windings are called "Primary" and "Secondary" windings.

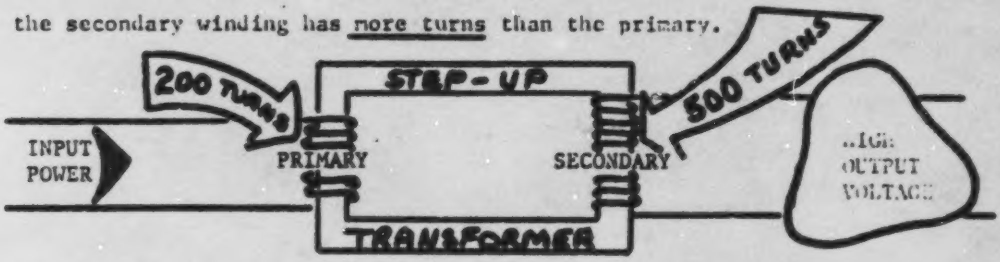


PRIMARY	The power to be transferred is placed in the primary winding.
SECONDARY	Power, at the desired voltage level, is removed from the secondary winding, and delivered to the device requiring this particular voltage.



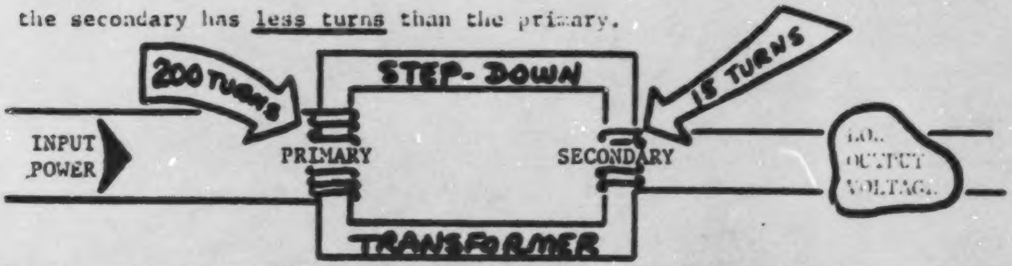
STEP-UP TRANSFORMERS

The output power of a transformer will be at a higher voltage, when the secondary winding has more turns than the primary.



STEP-DOWN TRANSFORMERS

The power output of a transformer will be at a lower voltage, when the secondary has less turns than the primary.



Q-7 a. The input power goes to the ________________ winding.
b. The output power comes from the ____________________ winding.
c. T-F Adding turns to the secondary winding will increase the output voltage from the transformer.
d. T-F All transformers step-up or step-down the voltage.

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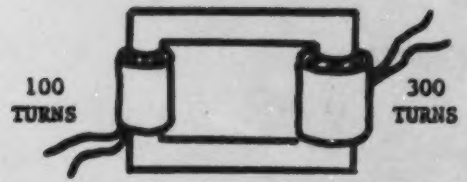
A-6 a. True
b. False...a "stationary" magnetic field.
c. current (also the type of core)

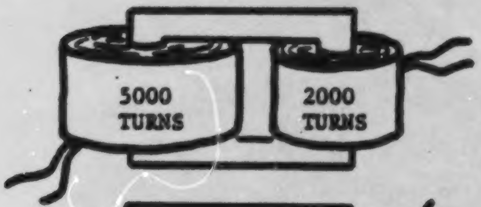
TRANSFORMER TURNS RATIO

The number of primary and secondary turns is most important to transformer operation. Often the actual number of turns is indicated, however more often, the "turns ratio" is used to indicate the expected performance of the transformer.

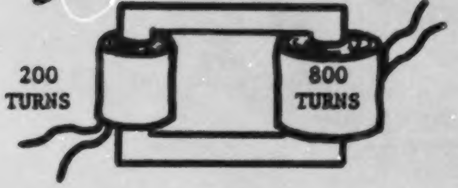
TURNS RATIO



= 1:3 Said as "One to Three"



= 5:2 Said as "Five to Two"



= 1:4 Said as "One to Four"

1:3

A turns ratio of 1:3 would indicate a step-up transformer. For every one turn in the primary, there are three turns in the secondary.

5:2

A 5:2 transformer would be a step-down transformer. For every 5 turns in the primary, there are 2 turns in the secondary.

1:4

Transformers with a 1:4 turns ratio are step-up. For every one turn in the primary, there are 4 turns in the secondary.

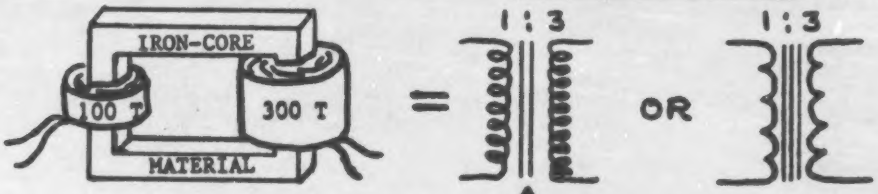
Q-8 a. A turns ratio of 3 : 4 indicates a step ________ transformer.
b. A turns ratio of 5 : 1 indicates a step ________ transformer.
c. T-F A turns ratio of 6 : 3 is the same as a turns ratio of 2 : 1
d. T-F Adding turns to the primary winding would reduce the output voltage from the secondary winding.

A-7 a. Primary
b. Secondary
c. True
d. Most of the time "true" but a special type called the isolation tfmr has no change.

TRANSFORMER SCHEMATIC SYMBOLS

The basic transformer schematic symbol depends upon the type of core material used.

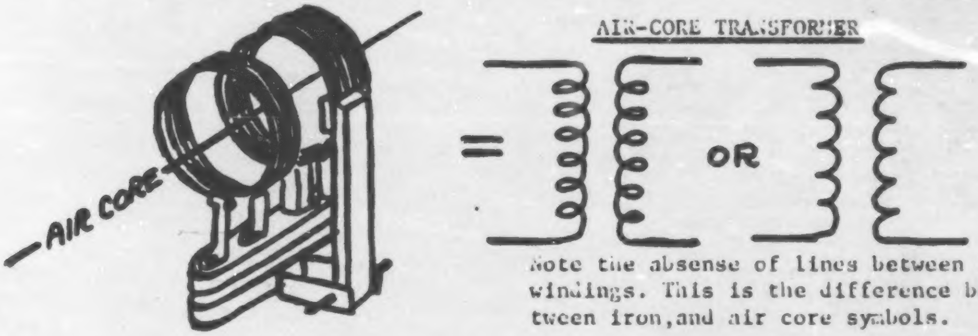
IRON-CORE TRANSFORMER



The number of vertical lines 2, 3, or 4 is not important.

Although all low frequency transformers have iron-cores, those designed to operate at the higher radio frequencies will have air-cores.

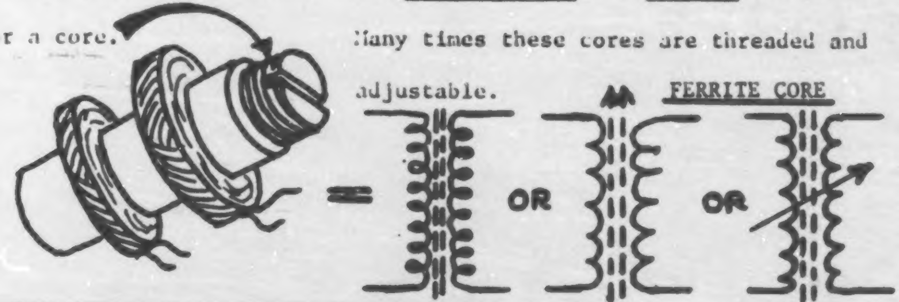
AIR-CORE TRANSFORMER



Note the absense of lines between the windings. This is the difference between iron,and air core symbols.

Often, transformers operating at radio frequencies, and other special purpose types will use a powdered-iron, or ferrite material for a core. Many times these cores are threaded and adjustable.

FERRITE CORE



Q-8 a. All low frequency transformers use an ______ core.
b. Air core transformers are used at the higher ____ frequencies.
c. T-F Iron core transformers are used at radio frequencies.
d. T-F Adding an iron core changes the turns-ratio.

A-8 a. up c. True... 4:2 is the same as 2:1, 9:3 = 3:1 etc..
b. down d. True... it changes the turns-ratio.

TRANSFORMER VOLTAGE CALCULATIONS

The secondary "output" voltage of a transformer depends upon the primary "input" voltage and the turns-ratio. The following transformer equation is used to calculate the secondary voltage.

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

E_p = Primary Voltage

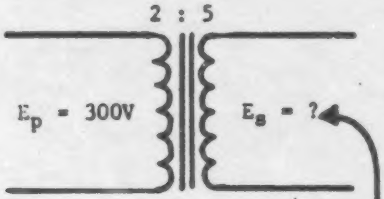
E_s = Secondary Voltage (To be calculated)

N_p = Primary Turns

N_s = Secondary Turns

(N_p, N_s:) Usually expressed as the turns-ratio.

EXAMPLE #1 Solve for $\boxed{E_s}$



$\frac{E_p}{E_s} = \frac{N_p}{N_s}$ Voltage-Turns Equation

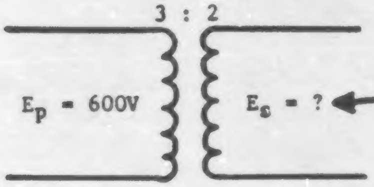
$\frac{300}{x} = \frac{2}{5}$ Values entered into the equation, with E_s as "x".

$\frac{300}{x} = \frac{2}{5}$ Cross-Multiply

$2x = 1500$ Divide for answer $\frac{2x}{2} = \frac{1500}{2}$

$x = \boxed{750 \text{ Volts}}$

EXAMPLE #2 Solve for $\boxed{E_s}$



$\frac{E_p}{E_s} = \frac{N_p}{N_s}$ Voltage-Turns Equation

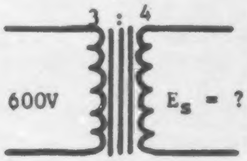
$\frac{600}{x} = \frac{3}{2}$ Values entered into the equation, with E_s as "x".

$3x = 1200$ Cross-multiply & divide for answer.

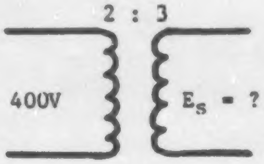
$x = \boxed{400 \text{ V}}$

Q-10 Solve the following for secondary voltage.

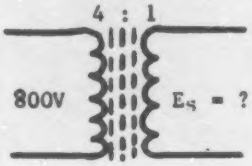
(a)



(b)



(c)

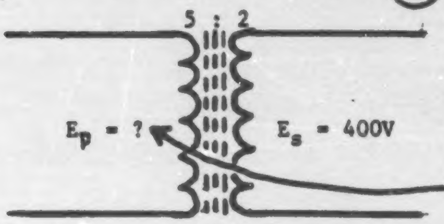


A-9	a. iron	c. False
	b. radio	d. False...it may change the weight though.

TRANSFORMER VOLTAGE CALCULATIONS (cont)

From the basic voltage-turns equation, other missing values can be calculated. The following examples show how this is done.

EXAMPLE #3 Solve for E_p



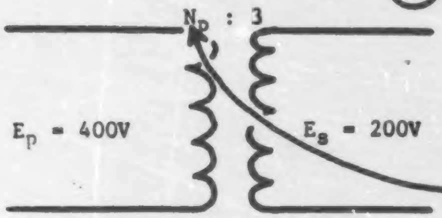
$\frac{E_p}{E_s} = \frac{N_p}{N_s}$ Voltage-turns equation

$\frac{x}{400} = \frac{5}{2}$ Values entered into the equation, with E_p as "x".

$2x = 2000$ Cross-multiply and divide for the answer.

$x = 1000$ volts

EXAMPLE #4 Solve for N_p



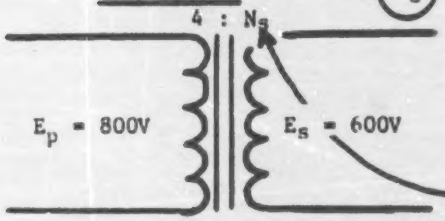
$\frac{E_p}{E_s} = \frac{N_p}{N_s}$ Voltage-turns equation

$\frac{400}{200} = \frac{x}{3}$ Values entered into the equation, with N_p as "x".

$200x = 1200$ Cross-multiply & divide for answer.

$x = 6$

EXAMPLE #5 Solve for N_s



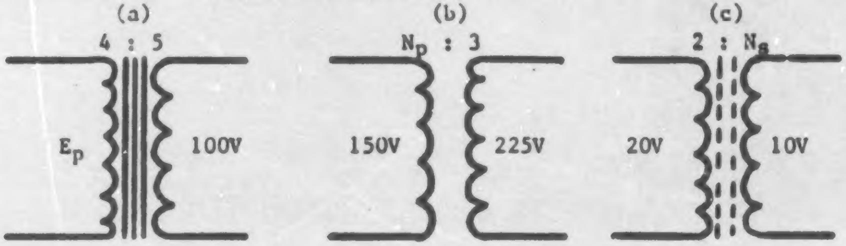
$\frac{E_p}{E_s} = \frac{N_p}{N_s}$ Voltage-turns equation

$\frac{800}{600} = \frac{4}{x}$ Values entered into the equation, with N_s as "x".

$800x = 2400$ Cross-multiply & divide for answer.

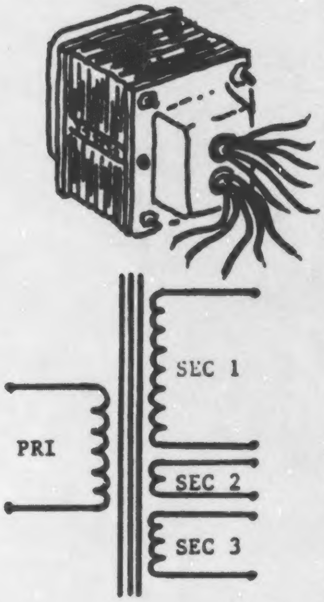
$x = 3$

Q-11 Solve for the indicated missing value. Try not to refer to the examples above, unless **necessary**.



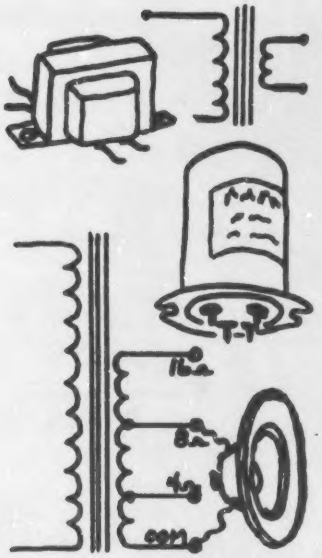
A-10 a. 800V b. 600V c. 200V

TRANSFORMER TYPES



POWER TRANSFORMERS

Transformers designed specifically for use at "Power Frequencies", are classified as Power Transformers. They have heavy laminated iron cores, and usually have more than one secondary winding. These transformers change the 120 volt line power, into several higher and lower voltage levels, which a particular type of electronic equipment will need to function properly. The separate windings operate independently, and can be checked individually for performance.



AUDIO TRANSFORMERS

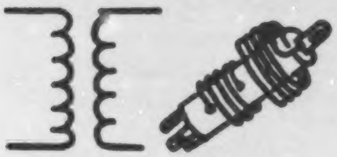
Speech, code, tones, and music frequencies are transfered thru Audio Transformers. Designed for operation up to 20,000 Hz, they also have laminated iron cores. Most audio transformers have only one secondary winding. Some have connections to various points on the secondary. These are called "taps". An example would be the "Audio Output Transformer", which transfers power from an Audio Amplifier electronic circuit, to a particular speaker. The two wires of an "8 Ohm speaker", would be connected to the "8 Ohm tap" and the Com (common) terminal.

-12 a. Power transformers usually have more than one _______ winding.
b. T-F Power transformers used a powdered iron core.
c. Upon entering electronic equipment, the line voltage first encounters a __________ transformer.
d. T-F Audio transformers have laminated iron cores.
e. T-F Audio transformers will not operate at power frequencies.

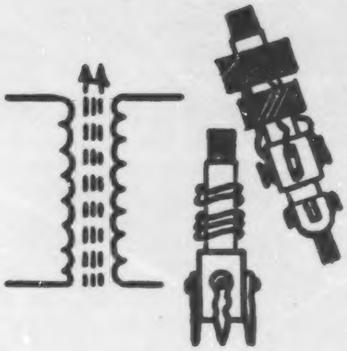
A-11 a. 80V b. $N_p = 2$ c. $N_s = 1$

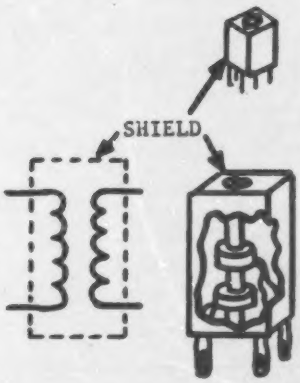
TRANSFORMER TYPES (cont)

RADIO FREQUENCY (RF) TRANSFORMERS



Radio receivers and transmitters contain many RF Transformers. They transfer power, at radio-frequencies, between sensitive electronic circuits. Designed for use from 20KHz, thru VHF and UHF frequencies, these transformers have powdered-iron, ferrite, or air cores. (Laminated iron cores will not work properly due to the rapidly changing magnetic fields at these higher frequencies.) Sizes range from large high-voltage, high-frequency types used in powerful transmitters, to miniature low-voltage transformers used in transistorized receivers. They can be identified by a few turns of insulated wire, wound on a common tubular form. Often, a threaded ferrite core passes thru both primary and secondary windings to adjust the transformers operation. Many RF Transformers are surrounded by metal shielding material, preventing interference, to and from nearby electronic components.





Q-13 a. Transformers designed to operate at the higher radio frequencies, are called ______ ________________ transformers.
b. T-F All RF transformers use an air core.
c. T-F Some RF transformers use a laminated iron core.
d. Many radio frequency transformers are surrounded by a __________ , to prevent interference.
e. T-F RF transformers have turns-ratios.
f. T-F RF transformers will work at audio frequencies.

A-12	a. secondary	e. False...they will operate at power frequencies, the most common of which are 60Hz and 400Hz. These are within the audio portion of the frequency spectrum.
	b. False	
	c. Power	
	d. True	

TRANSFORMER CURRENT CALCULATIONS

The amount of current flowing thru the primary winding depends on the amount of secondary current, and the turns-ratio. The following transformer equation is used to calculate primary current.

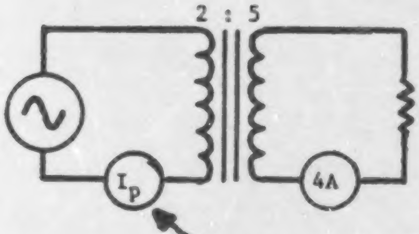
$$\frac{N_p}{N_s} = \frac{I_s}{I_p}$$

N_p = Primary Turns
N_s = Secondary Turns
} Usually expressed as the turns-ratio.

I_s = Secondary Current

I_p = Primary Current (To be calculated)

EXAMPLE #6 Solve for I_p



$\frac{N_p}{N_s} = \frac{I_s}{I_p}$ Current-Turns Equation

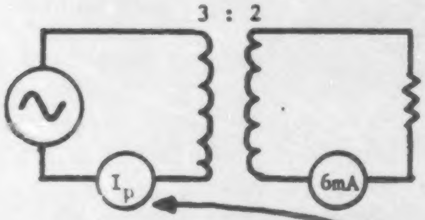
$\frac{2}{5} = \frac{4}{x}$ Values entered into the equation, with I_p as "x".

$\frac{2}{5} = \frac{4}{x}$ Cross-Multiply

$2x = 20$ Divide for answer

$x = \boxed{10 \text{ Amps}}$

EXAMPLE #7 Solve for I_p



$\frac{N_p}{N_s} = \frac{I_s}{I_p}$ Current-Turns Equation

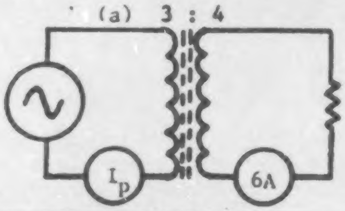
$\frac{3}{2} = \frac{6}{x}$ Values entered into the equation, with I_p as "x".

$3x = 12$ Cross-multiply & divide for the answer

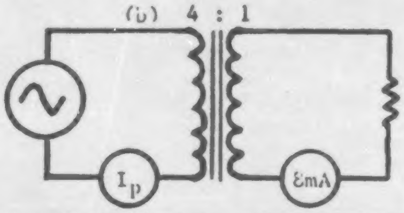
$x = \boxed{4\text{mA}}$

Q-14 Solve the following for primary current.

(a) 3 : 4



(b) 4 : 1



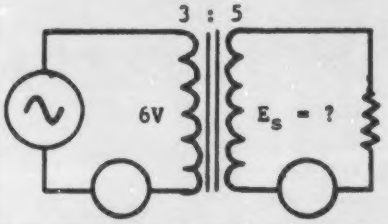
A-13
a. radio frequency
b. False...some have powdered iron
c. False...never laminated iron
d. shield
e. Of course they do.
f. False, frequency too low.

VOLTAGE-TURNS & CURRENT-TURNS CALCULATIONS

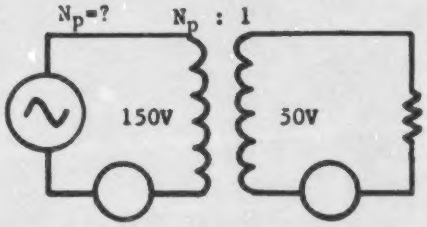
Q-15 Solve the following problems, using the Voltage-Turns Equation.

$$\boxed{\frac{E_P}{E_S} = \frac{N_P}{N_S}}$$

(a)



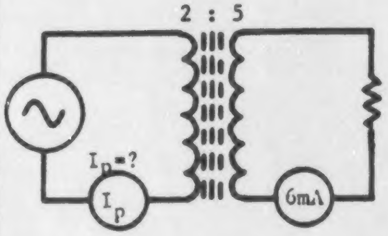
(b)



Q-16 Solve the following problems, using the Current-Turns Equation .

$$\boxed{\frac{N_P}{N_S} = \frac{I_S}{I_P}}$$

(a)



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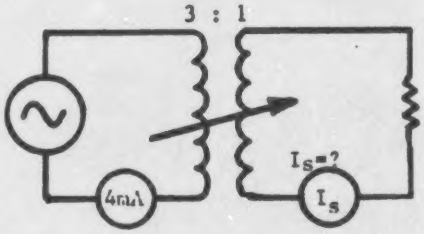
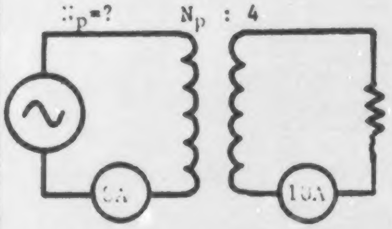
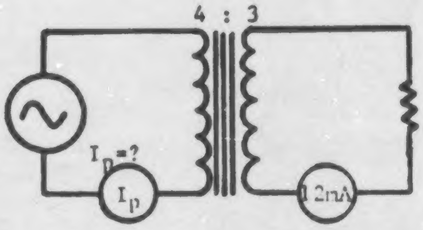


(c)



(d)



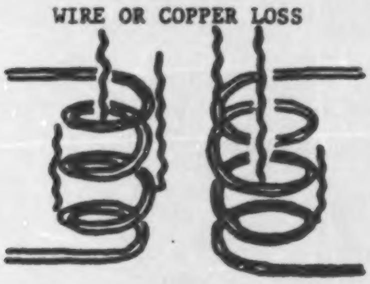
A-14

a. 8A b. 2mA

"WASTED HEAT IS POWER LOST"

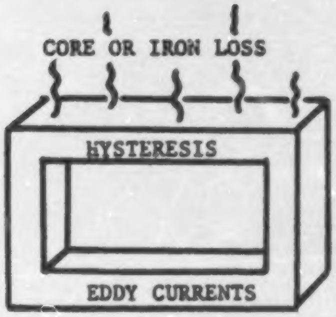
TRANSFORMER POWER LOSSES

Heat given off by a transformer while operating, indicates that there are some losses involved when power is being transferred.



COPPER LOSS

The DC resistance of copper wire, causes some power loss. Power Loss = $I^2 \times R$ The equation indicates that the use of low resistance (larger diameter) wire, reduces this loss to a minimum.



CORE LOSSES

Iron-core transformers have two additional power losses.

HYSTERESIS LOSS.......The constant, and rapid re-alignment of the core magnetic materials causes a power loss. This is reduced, by using a core material with high "permeability".

EDDY CURRENT LOSS.....Moving magnetic fields of the transformer, "cut" thru the core material, inducing a useless current within the iron. This current can be reduced by raising the core resistance. Laminating, or thin slicing, works well at low frequencies, while at radio frequencies, powdered-iron or ferrite materials are used.

100%

Thru excellent transformer engineering and design, the losses discussed have been reduced to such a low value, they are ignored during calculations. Transformers may be assumed to be very near 100% efficient.

Q-17 a. Eddy current losses are reduced by _______________ the core.
b. Larger diameter wire is used to reduce the ____________ loss.

A-15

a. 10V b. $N_p = 3$

A-16 a. 15mA c. 5A

b. 12mA d. 9mA

VOLTAGE-CURRENT CALCULATIONS

Another commonly used equation, is that which considers the levels of voltage and current within a transformer circuit.

$$\frac{E_P}{E_S} = \frac{I_S}{I_P}$$

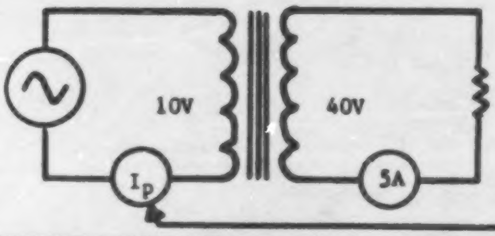
E_p = Primary Voltage

E_s = Secondary Voltage

I_s = Secondary Current

I_p = Primary Current

EXAMPLE #8 Solve for (I_p)



$\frac{E_p}{E_s} = \frac{I_s}{I_p}$ Voltage-Current Equation

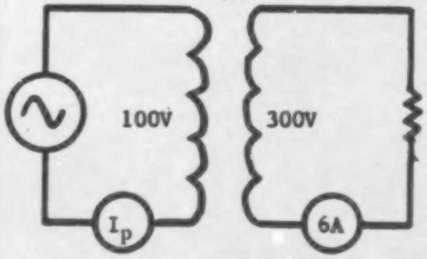
$\frac{10}{40} = \frac{5}{x}$ Values entered into the equation, with I_p as "x".

$10x = 200$ Cross-multiply and divide for answer.

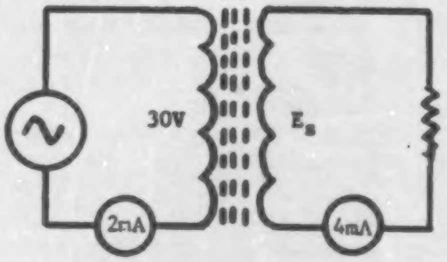
$x = \boxed{20 \text{ Amps}}$

Q-18 Solve for the indicated voltage or current level.

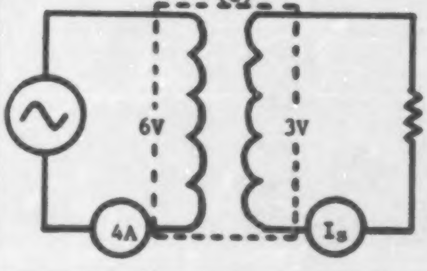
(a)



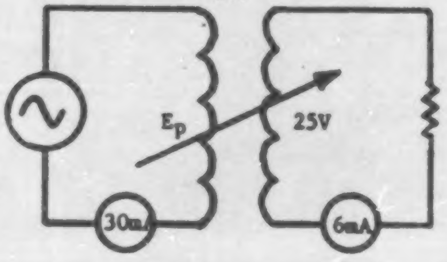
(b)



(c)



(d)

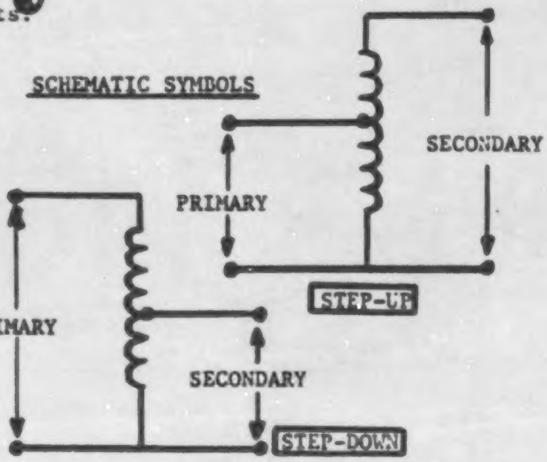


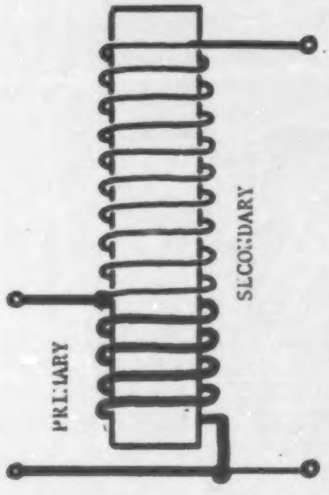
A-17 a. laminating....each lamination is insulated from the others.
b. copper or wire loss.

AUTO-TRANSFORMERS

The autotransformer differs from other transformers in that it has only one winding, rather than two or more as in ordinary transformers. Often constructed to be variable, they are sometimes referred to as Variacs® or Powerstats®.

SCHEMATIC SYMBOLS





STEP - UP
AUTOTRANSFORMER

An alternating magnetic field, produced by the primary current, induces a voltage into the remaining part of the single winding.

As the primary and secondary "share" part of the winding, autotransformers can be constructed physically smaller than separate winding types. However, autotransformers DO NOT "isolate" the primary and secondary circuits, and cannot be used in many applications.

Q-19 a. Autotransformers are constructed with only _______ winding.
b. T-F For the same power rating, autotransformers can be constructed physically smaller than ordinary transformers.
c. T-F Autotransformers "isolate" the primary and secondary circuits.
d. T-F Autotransformers can be either step-up or step-down types.

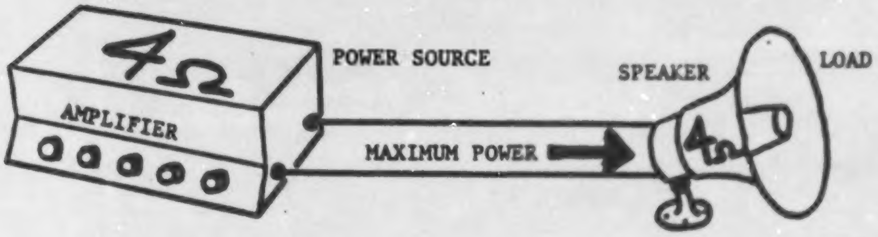
A-18

a. $I_p = 18A$ b. $E_s = 15V$ c. $I_s = 8A$ d. $E_p = 5V$

MAXIMUM POWER TRANSFER

To transfer the maximum possible amount of power from one part of an electronic circuit to another, a certain condition MUST be met.

★ The opposition (Ω) of the "load" must be the same as the opposition (Ω) of the "source". ★



Every source of electrical power has some amount of resistance contained within it.

The conductors of an AC Generator have a definite amount of wire resistance.

The chemical "electrolyte" of a Battery, has a varying resistance, depending on the "charge".

The semi-conductor material of a Solar Cell has resistance, depending on the amount of light.

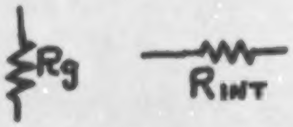
All radio tubes and transistors have individual resistances, depending on the type.

This unavoidable, "built-in" resistance of a power source is called INTERNAL RESISTANCE.

R_g = internal resistance of a generator

R_s = internal resistance of the source

R_{int} = internal resistance



Q-20 a. T-F Every source of power has an internal resistance.

b. For maximum power transfer to occur, the opposition of the source and the opposition of the load must be______________.

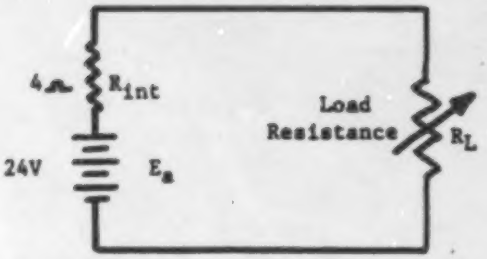
c. T-F Tubes and transistors do not have internal resistance.

A-19 a. one
b. true....as part of the copper conductors are "shared".
c. False...there is "metal-to-metal contact between the circuits.
d. True

MAXIMUM POWER TRANSFER (cont)

This principle: "The opposition of the source and load, must be matched".....leads to some difficulties in the design of electronic equipment.

To better show this point, consider a simple 2 resistance circuit.



Remember the principle... maximum power will be delivered to the load, when its opposition is the same as the opposition of the source.

The following chart clearly proves this basic principle.

LOAD RESISTANCE (Variable)

TOTAL RESISTANCE ($R_L + R_{int}$)

TOTAL CURRENT (E_a/I_t)

R_L	R_t	I_t		LOAD RESISTOR POWER
0Ω	4Ω	6a	→	$I^2 \times R_L$ = 0 Watts
2Ω	6Ω	4a	→	$I^2 \times R_L$ = 32 Watts
4Ω	8Ω	3a	→	$I^2 \times R_L$ = 36 Watts
8Ω	12Ω	2a	→	$I^2 \times R_L$ = 32 Watts
20Ω	24Ω	1a	→	$I^2 \times R_L$ = 20 Watts

MAXIMUM POWER TRANSFER

The load (4Ω), receives maximum power, 36 watts when it is the same as the internal (4Ω) resistance of the source.

This is not a simple "coincidence" of numbers. It is an essential fact concerning all electronic circuits.

Q-21 a. For maximum power transfer to occur, the opposition of the source and the opposition of the load must be ______________.
b. T-F All sources of power, including batteries, have resistance.
c. T-F Maximum power transfer is accomplished in DC circuits only.
d. T-F It is a requirement that in all electronic circuits, maximum power transfer must take place.

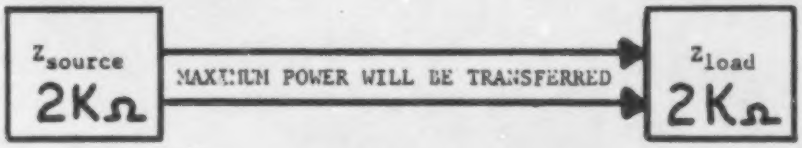
A-20 a. True...at least every source of electrical power does.
b. equal, the same, matched....or words to that effect.
c. False....they all have some amount of internal resistance.

IMPEDANCE MATCHING

The source of power contains Resistance (R), and combinations of Reactance (X_L & X_C). "Lumped" together, these oppositions form a total.....called IMPEDANCE (Symbol Z)

The load also contains not only Resistance (R), but often combinations of Reactances (X_L & X_C) as well. These oppositions "lumped" together form the load IMPEDANCE (Symbol Z).

If the principle of MAXIMUM POWER TRANSFER is to apply............ ....the IMPEDANCE (Z) of the load must be "matched" to the IMPEDANCE (Z) of the source.



Seems easy???......sure it is...IF...the two impedances are matched.

BUT.....

99% of the time, the two impedances are very different. Example: Source Impedance = 2,000Ω Load Impedance = 10Ω Under this condition, only a very small transfer of power would be accomplished.

One electronic component, the TRANSFORMER, is capable of solving this power transfer problem.

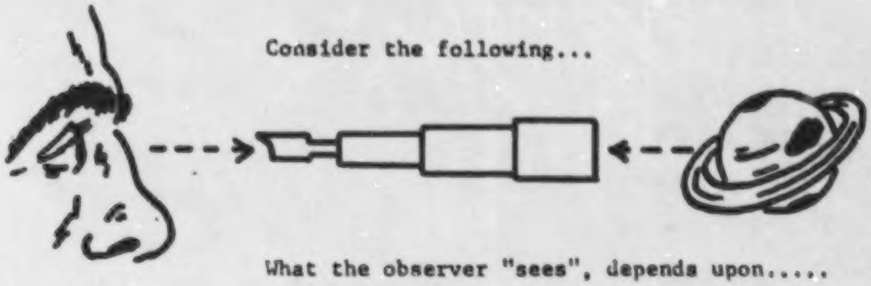
Q-22 a. "Impedance" is a combination of resistance and _____________.
b. T-F An increase of internal resistance would cause the source impedance to increase.
c. T-F Frequency can affect source and load impedances.
d. T-F In most circuits, the source and load impedances are equal or almost equal.

A-21 a. equal, the same, matched, or words to that effect.
b. True....especially batteries.
c. False...DC or AC circuits.
d. False...only in some circuits is it desired, not in all.

IMPEDANCE MATCHING (cont)

The selection of a proper "turns-ratio" transformer, can accomplish Maximim Power Transfer between two unlike impedances.

Consider the following...

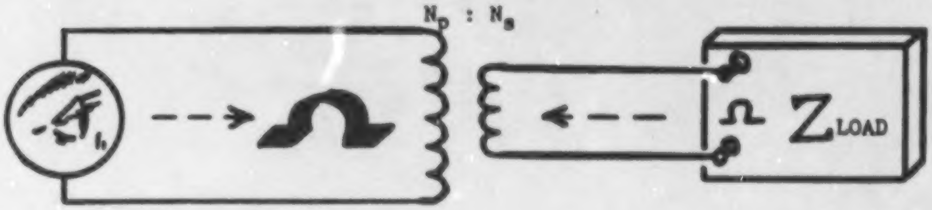


What the observer "sees", depends upon.....

(1) what's out there, and
(2) the lens ratio of the telescope.

Similarly, the opposition "seen" by the power source, depends on two factors.....

(1) the LOAD impedance (what's out there), and
(2) the TURNS-RATIO of the transformer.



The impedance (Ω) seen by the power source is called PRIMARY IMPEDANCE. (Symbol Z_p)

The load impedance is called the SECONDARY IMPEDANCE. (Symbol Z_s)

The impedance seen by the source, PRIMARY IMPEDANCE, can be calculated using this equation.

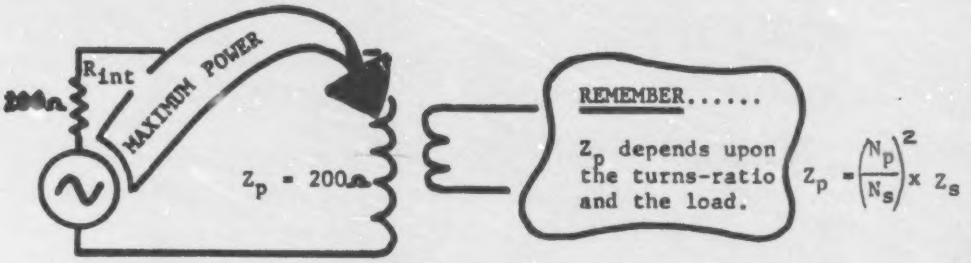
$$Z_P = \left(\frac{N_P}{N_S}\right)^2 \times Z_S$$

Q-23 a. The opposition "seen" by the power source is called ________.
b. What two factors determine the amount of Primary Impedance seen by the power source? ______________and________________
c. T-F Primary and secondary impedances are usually equal.

A-22
a. reactance or reactances.
b. True...the source impedance is the internal resistance mostly.
c. True...as it would affect the X_C and X_L of the reactances.
d. False...usually they are pretty far apart.

IMPEDANCE MATCHING (cont)

When Z_p is equal to R_{int}, MAXIMUM power will be transferred from the power source to the transformer primary winding.

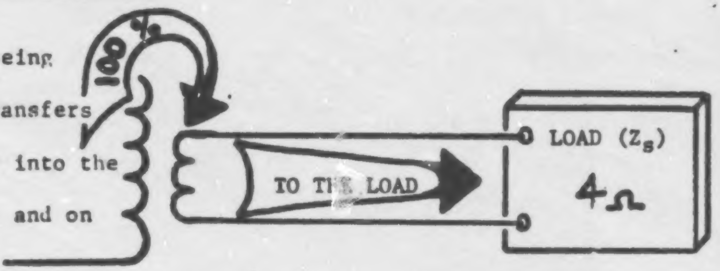


REMEMBER......

Z_p depends upon the turns-ratio and the load.

$$Z_p = \left(\frac{N_p}{N_s}\right)^2 \times Z_s$$

The transformer, being 100% efficient, transfers this maximum power into the secondary winding, and on to the load.



Thus, by using the proper transformer, maximum power can be transferred between two widely different impedances, without any loss.

REFLECTED IMPEDANCE

$$Z_p = \left(\frac{N_p}{N_s}\right)^2 \times Z_s$$

In the equation, it will be noted that, any change in Z_s will affect the answer Z_p. That is to say, any change in the opposition of the load would cause a change to the primary impedance. This shift of primary impedance by any change in the secondary is referred to as REFLECTED IMPEDANCE. (Symbol Z_{REF})

Q-24
a. T-F Maximum power transfer will occur when the primary impedance is the same as the internal resistance of the source.
b. Any change in the load impedance will cause a change to occur in the ________________ impedance.
c. T-F Reflected impedance is the load impedance.

A-23
a. Primary Impedance or just "impedance".
b. The "load" or secondary impedance, and the turns-ratio.
c. False...usually very different.

REFLECTED IMPEDANCE (cont)

As any variation in the load impedance will cause a change of primary impedance, it can be said that the primary impedance is actually a "reflection" of what is going on in the secondary.

Therefore, the Reflected Impedance IS the primary impedance, and can be calculated using the same equation.

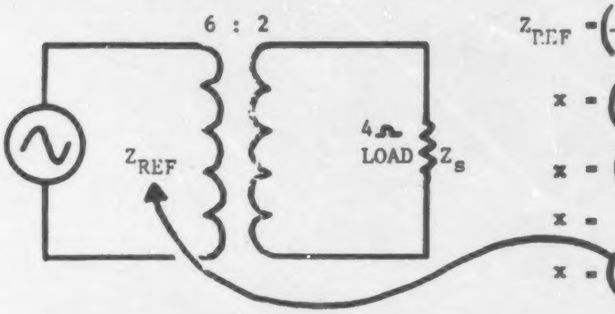
$$\boxed{Z_{REF} = \left(\frac{N_P}{N_S}\right)^2 \times Z_S}$$

Z_{REF} = Reflected Impedance (To be Calculated)

N_p = Primary Turns
N_s = Secondary Turns
} Turns-Ratio

Z_s = Secondary Impedance (The opposition of the load)

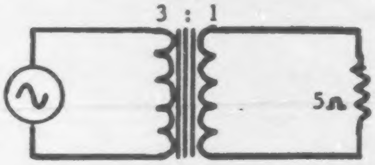
EXAMPLE #9 Solve for $\boxed{Z_{REF}}$



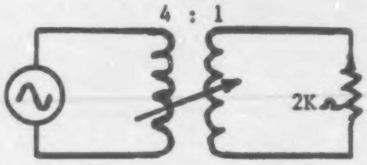
$Z_{REF} = \left(\frac{N_p}{N_s}\right)^2 \cdot Z_s$	Z_{REF} Equation
$x = \left(\frac{6}{2}\right)^2 \cdot 4$	Values entered with Z_{REF} as x
$x = (3)^2 \cdot 4$	Division done
$x = 9 \cdot 4$	Square 3 and Multiply for answer.
$x = \boxed{36\,\Omega}$	

Q- 25 Solve for the Reflected Impedance seen by the generator.

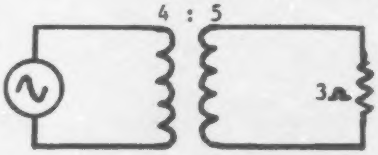
(a)



(b)



(c)



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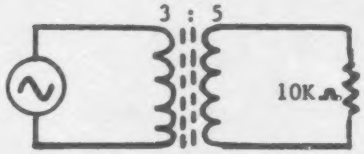
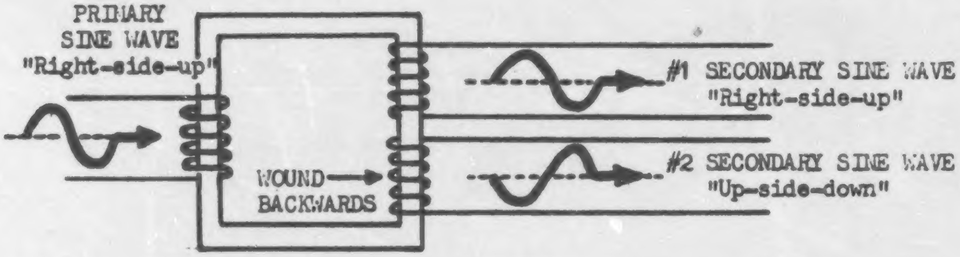


A-24 a. True....that's what it's all about.
b. Primary Impedance.
c. False....it's a change of Primary Impedance caused by the load.

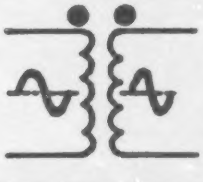
TRANSFORMER PHASE RELATIONSHIPS

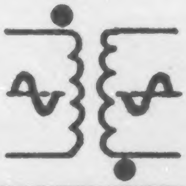
Some transformers will cause the "output" secondary voltage to be inverted. Some will not. It depends upon how the transformer is wound.

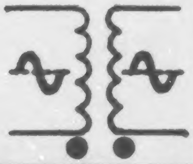


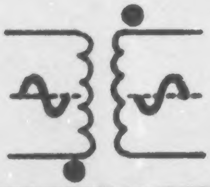
The output of Secondary #1, is said to be "in-phase" with the primary. The output of Secondary #2, is said to be 180° "out-of-phase" with the primary. 180° "out-of-phase" means, up-side-down from the Primary, or inverted from the Primary.

The phase relationship between Primary and Secondary is indicated by "dots". If the "dots" are both on the top, or both on the bottom of the schematic, the output will be the same as the Primary sine wave. However, if one "dot" is on top, and the other "dot" is on the bottom, the output sine wave will be 180° out-of-phase, inverted, or upside-down from the Primary sine wave.

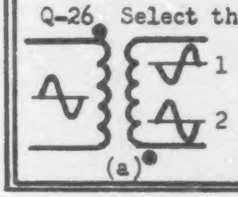




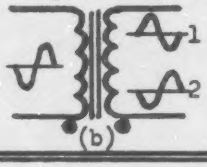




Q-26. Select the "output" sine wave, with the correct phase relationship.



(a)



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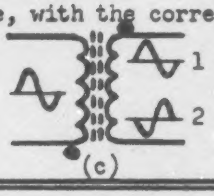
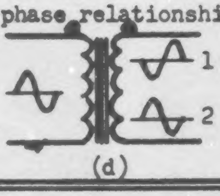


(c)



(d)

A-26 a. 1 b. 2 c. 2 d. 2

TROUBLESHOOTING TRANSFORMERS

Common transformer troubles fall under three catagories:

(1) Shorted Windings

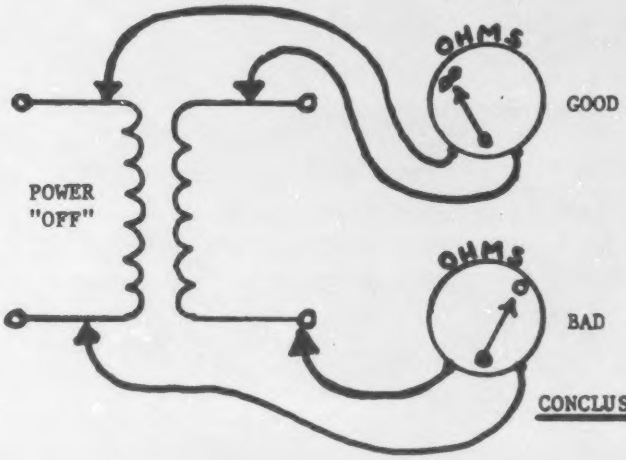
(2) Open Windings

(3) Winding-to-core Short

SHORTED WINDINGS

The entrance of moisture, and arcing or overheating due to other electrical problems, can cause "failure" of the insulation on transformer windings. This allows the primary and secondary copper conductors to come into contact with each other. Usually this will cause other serious trouble or component damage within the equipment.

"Continuity" between the primary and secondary windings can be easily determined using an Ohmmeter.



No deflection of the ohmmeter (∞ OHMS), indicates a "no continuity" normal condition.

Full scale deflection, (0 or near 0Ω), indicates continuity between windings. (BAD)

CONCLUSION: Primary and secondary windings "shorted" together.

With the exception of Autotransformers, an ohmmeter should never indicate any "continuity" between primary and secondary windings.

Q-27 a.T-F Continuity means a complete path for current to flow.
b.T-F Ohmmeters are used to check continuity.
c. There should be no continuity between windings, except in the ________ transformer, due to its single winding.

A-26

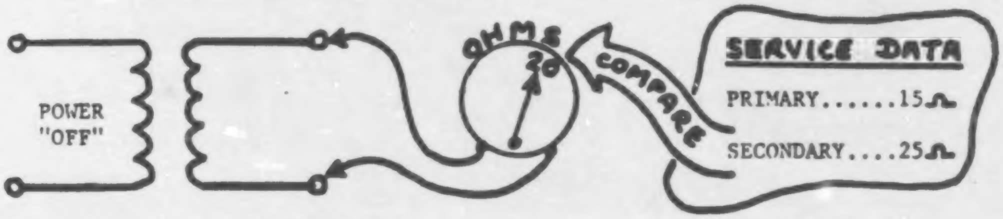
a. 1 b. 1 c. 2

SHORTED WINDINGS (cont)

Two or more turns of the primary winding may come into metal-to-metal contact with each other if "insulation failure" occurs. This reduces the primary "wire resistance", and upsets the transformer performance. Of course, primary windings shorted together would change the turns-ratio, and show up as inaccurate secondary voltage readings and circuit malfunction.

Shorted turns in the secondary would give the same results.

Ohmmeter resistance checks can be made, comparing the readings with those given in the service data for the equipment.



CONCLUSION: Some secondary turns "shorted".

Although seldom occuring, a complete "short" of the primary or secondary windings is possible. In such cases, total failure of the transformer is experienced, with a blown-fuse or "plenty of smoke" as the symptom. The bad winding would read ZERO OHMS.

It is common that even an ohmmeter resistance check will not detect a defective transformer, and direct substitution with a known good replacement is the only "sure" troubleshooting method that works.

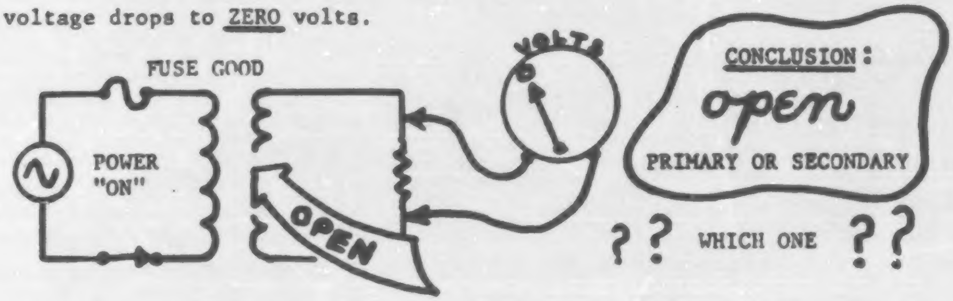
Q-28
a. T-F There should never be any metal-to-metal contact between the turns of a transformer winding.
b. T-F A transformer winding should never have continuity.
c. T-F Shorted turns in a transformer winding will affect the turns-ratio and the reflected impedance.
d. T-F No deflection on the ohmmeter needle indicates a good transformer winding.
e. T-F Ohmmeter checks always detect transformer troubles.

A-27 a. True
b. True...another meter called a "megger" is also used
c. autotransformer.

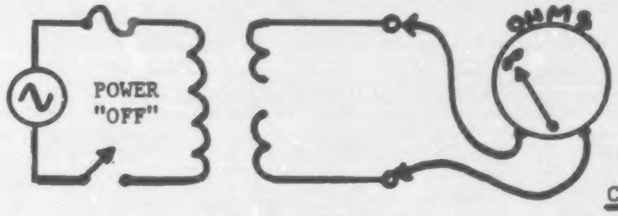
OPEN WINDINGS

Easier to detect and troubleshoot, is the "open" primary or secondary transformer winding. Any "break" in the conductors, caused by electrical failure or physical damage, would result in immediate and total failure of the transformer. The circuit in which it operates would cease to function completely.

Should the primary or secondary winding "open", the secondary voltage drops to ZERO volts.



Resistance checks will determine which winding is "open".



No deflection of the ohmmeter needle (∞ Ω), indicates that the secondary winding lacks "continuity".

CONCLUSION: Secondary "open".

Most often a transformer winding will "open" following an insulation failure. Internal arcing "melts" the copper conductor of a winding, causing the open. Sometimes a winding "opens" due to excessive physical strain on its connecting leads. Always use care when installing a replacement transformer. Avoid "pulling" on the leads.

Q-29 a. T-F An open transformer winding has continuity.
b. The first indication of an open winding is the ___________ voltage dropping to zero, and circuit malfunction.
c. T-F If the secondary winding "opens", the primary voltage will drop to zero.
d. T-F An open winding will blow the fuse in the primary circuit.

A-28
a. True
b. False...always has continuity.
c. True...and mess-up the circuit.
d. False...an open winding.
e. False...not always.

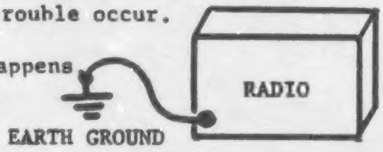
WINDING-TO-CORE SHORT

Iron core transformers, particularly those involved with high voltages, may develop a trouble which can create an unsafe condition.

A winding, shorted to the iron core....

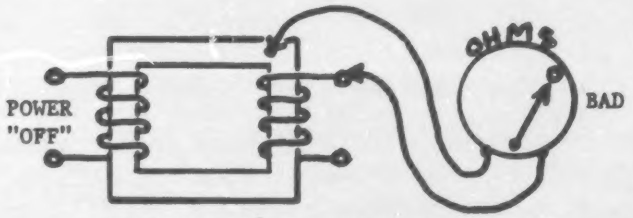
An iron-core transformer is normally bolted to the chassis. Continuity between a winding and the core, may place hazardous voltage levels on the chassis. (From the winding...to the core...to the chassis)

"Grounding" of the equipment is therefore necessary to protect personnel from electric shock should this trouble occur.



When such a short (winding to core) happens, connecting circuits become inoperative, excessive heating and smoking may begin, and fuses or circuit-breakers perform their function, protecting the equipment from furthur damage.

If this type of "short" is suspected, a continuity-check with an ohmmeter will confirm the trouble.



Full deflection of the ohmmeter needle indicates continuity between the winding and the iron-core.

CONCLUSION: The secondary winding is "shorted" to the core.

There should NEVER be continuity between a winding, and the core material of any type of transformer.

Q-30
a. Winding-to-core shorts cause an ________ condition.
b. T-F When a winding-to-core short occurs, the secondary voltage will change and the circuit will not function.
c. T-F A winding-to-core short will always blow the fuse.
d. T-F Winding-to-core shorts are repairable.
e. T-F An ohmmeter is used to detect winding-to-core shorts.

A-29 a. False....just the opposite.
b. secondary
c. False....remember, the primary winding is connected to the power source, and it doesn't change.
d. False....it will reduce the primary current, and the fuse remains OK.

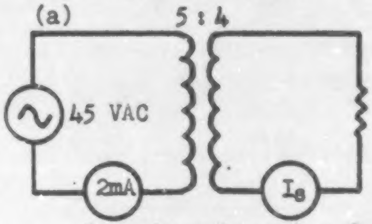
EQUATION SUMMARY

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \qquad \frac{E_p}{E_s} = \frac{I_s}{I_p} \qquad \frac{N_p}{N_s} = \frac{I_s}{I_p} \qquad Z_{ref} = \left(\frac{N_p}{N_s}\right)^2 \cdot Z_s$$

PROBLEM SUMMARY

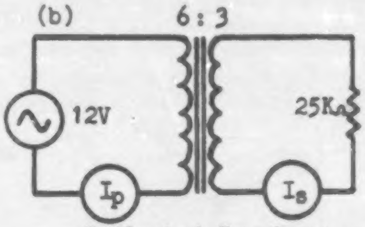
Q-31 Solve the following problems as indicated. Use the Equation Summary shown above.

(a)



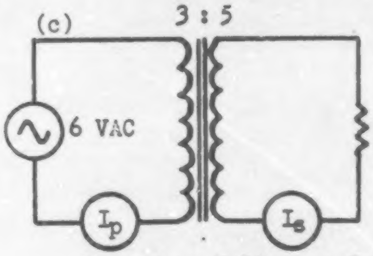
Secondary Current = ?

(b)



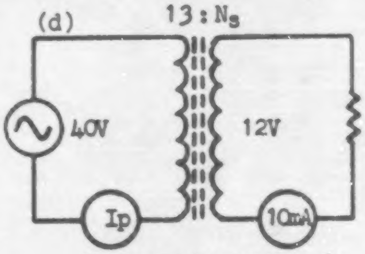
Reflected Impedance = ?

(c)



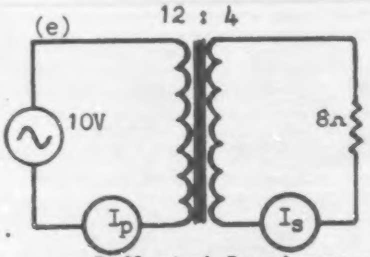
Secondary Voltage = ?

(d)



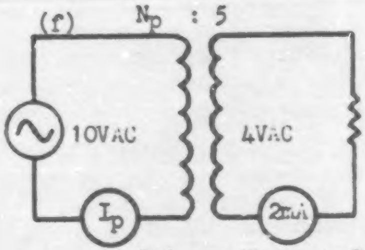
Primary Current = ?

(e)



Reflected Impedance = ?

(f)



Primary Turns = ?

A-30 a. unsafe
b. Not always....it depends a lot on the type of circuit.
c. Again, not always, but the unsafe condition still remains.
d. Not usually....replacement is the only sure repair.
e. True....remember to use it, with the power "off".

NOTE: Sorry for the "not always", and "not usually" etc.. Troubleshooting transformers is not a true-or-false proposition. There are just no "always true" or "always false" answers to be found for some of the common troubles. Replacement, often is the only "sure cure", and many times it's the only way to locate the trouble.

A-31 a. 2.5mA
b. 100KΩ
c. 10V
d. 3mA
e. 72Ω
f. 12.5 Turns (or 12.5 : 5 Ratio)

SUMMARY

The study of transformers does not END here...it only begins. Publications covering the subject in greater depth, are readily available in Technical Study Centers.

The importance of transformers in the operation of complex circuits, will become more apparent as the study of Electronics continues. Their basic functions of stepping-up, stepping-down, and impedance matching, are only a few of the tasks assigned to this component.

From the job of getting power to the radio, it also plays a major part in which station will be heard. The formation of a Radar signal, depends largely on the performance of many types of transformers. Airborne equipment, with its size and weight limittations, contains some of the more unusual and interesting transformer types.

The reliability of a well made transformer is an established fact, and only thru electrical or physical abuse do they rarely malfunction.

The TRANSFORMER....A step-up in the development of Electronics!

PREPARE THE MAN

ATC GP 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-16

Technical Training

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 16

RELAYS

1 May 1974

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

ATC Keesler 5-125

DO NOT USE ON THE JOB

Basic and Applied Electronics Department
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-16
1 May 1974

ELECTRONIC PRINCIPLES

MODULE 16

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

CONTENTS

TITLE	PAGE
Overview	1
List of Resources	2
Digest	3
Adjunct Guide	4
Module Self Check	7

* Supersedes KEP-GP-16, 1 November 1973. Use previous edition until exhausted.

OVERVIEW

RELAYS

1. SCOPE: This module explains the operation and functions of each part of the basic relay in electrical circuits.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

   a. Given a group of statements, select the one that describes the operation of a relay.

   b. Given a relay schematic with or without coil current, determine which contacts will be open and which will be closed.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK. IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, TURN TO THE NEXT PAGE AND PREVIEW THE LIST OF RESOURCES. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

LIST OF RESOURCES

RELAYS

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest

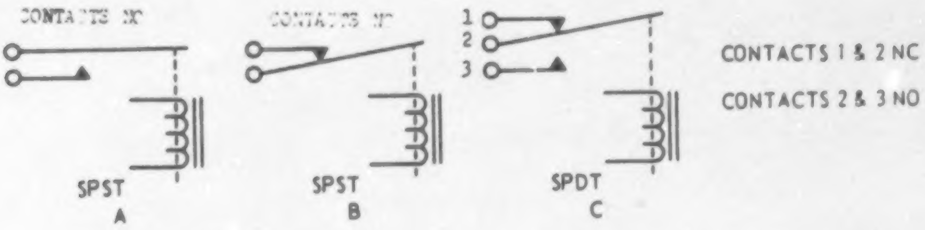
Adjunct Guide with Student Text

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

RELAYS

A relay is an electromechanical device. Relays are made in many forms or sizes and used in many types of control circuits. All electromagnetic relays operate on the principle that a piece of soft iron called an armature is attracted to the pole of an electromagnet when the pole becomes energized. This armature can engage one or more switch contacts. These switch contacts can be arranged in various configurations such as: Single pole single throw (SPST), Double pole double throw (DPDT), Single pole double throw (SPDT), and many other combinations.

Normally open contacts (NO) and normally closed contacts (NC) refer to contact conditions when the relay is de-energized.



REP4-1015

Figure 16-1.

Figure 16-1 shows all relays in the de-energized condition with the contacts open or closed as indicated. When energized the normally open contacts will close and the normally closed contacts will open.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ADJUNCT GUIDE

RELAYS

INSTRUCTIONS:

Study the reference materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the top of the next even numbered page following the questions.

If you experience any difficulty, contact your instructor.

Begin the program.

* * *

A. **Turn to Student Text, Volume II, and read paragraphs 5-1 thru 5-13. Return to this page and answer the following questions.**

1. **Which of the following are true concerning relays?**

   _____a. **The electrostatic principle is used.**

   _____b. **The electromagnetic principle is used.**

   _____c. **A moving armature opens or closes switch contacts.**

   _____d. **Never used as a remote control device.**

   _____e. **Uses a rotating armature and brushes.**

2. **Match the parts of basic relay shown with the appropriate term listed.**

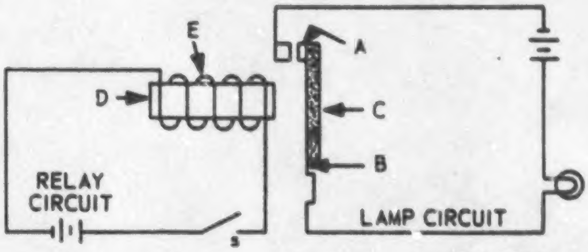
   Core ______________

   Coil ______________

   Armature ______________

   Spring ______________

   Contacts ______________



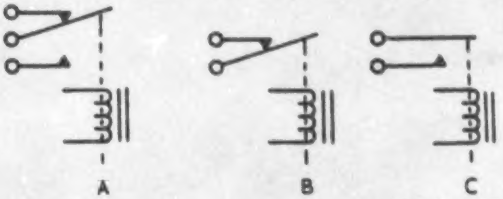
REP4-1016

3. **Match the type of contact arrangement shown below with the proper designation listed.**

   SPST NO ______________

   SPDT - ______________

   SPST NC ______________



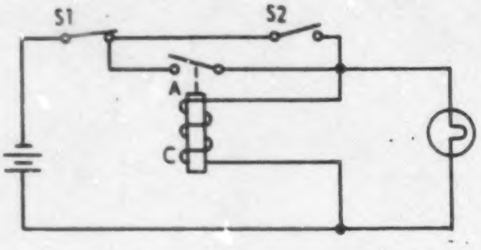
REP4-1017

4. Match the following relay circuits to the specific name listed.

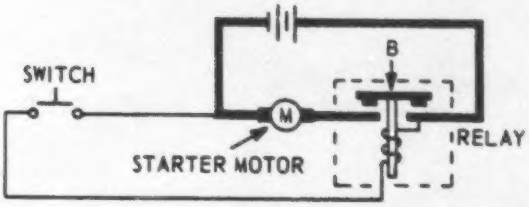
Starting ____________

Holding ____________

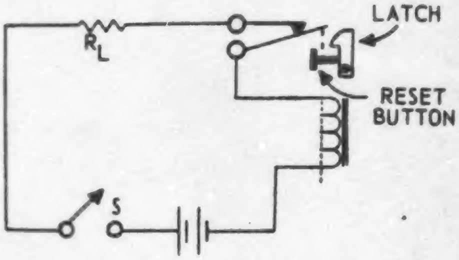
Overload ____________



A



B



C

REP4-1018

5. Which of the following would be used to clean the contact points of a relay when required?

_____a. Sandpaper

_____b. Burnishing tool

_____c. Gasoline

_____d. Napthalene

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

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ANSWERS TO A:

1. b, c
2. D, E, C, B, A
3. C, A, B
4. B, A, C
5. b

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

RELAYS

1. Indicate if true (T) or false (F).

______a. All relays are electromechanical devices which operate by permanent magnets attracting an armature which in turn opens and closes switches.

______b. A relay can be used as a remote control switch.

______c. Relays use the principle of an electromagnet attracting an armature.

______d. Relay contact points should be filed periodically to remove oxide buildup.

______e. A relay with an open coil could function because of residual magnetism.

______f. Open (or shorted) coils can be located by using an ohmmeter.

______g. Relays should be inspected and checked thoroughly and frequently.

______h. The starting relay on most autos is a holding relay.

______i. Relays are sometimes used as an overload device.

______j. Overload relays must be reset either manually or automatically once it is tripped.

______k. In a starting relay, a large control current is used to energize the relay coil that remotely controls the low current of the starter circuit.

______l. A relay armature can control several switches.

2. Identify the parts of the relay shown

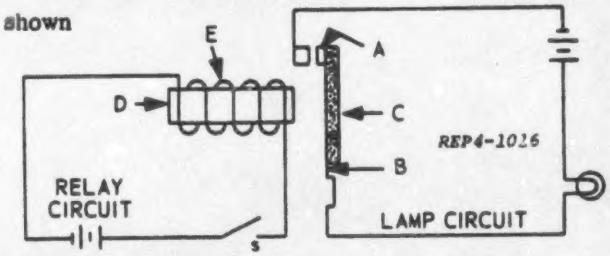
Core ____________

Armature ________

Spring __________

Contacts ________

Coil ____________

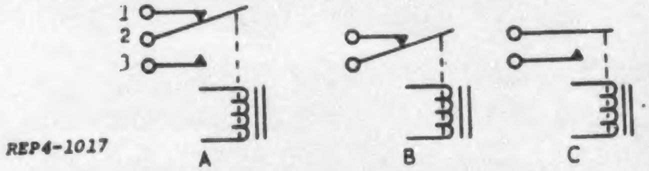


3. Match the following diagram of switch contacts to the proper designation.

SPST NO ________

SPST NC ________

SPDT __________



4. In the circuit 3A above, indicate which contacts are closed when the coil is energized.

______a. 1 and 2

______b. 1 and 3

______c. 2 and 3

______d. none, all open

CONFIRM YOUR ANSWERS ON THE NEXT EVEN NUMBERED PAGE.

MODULE SELF-CHECK

ANSWERS TO MODULE SELF-CHECK

1. a. F
   b. T
   c. T
   d. F
   e. F
   f. T
   g. T
   h. F
   i. T
   j. T
   k. F
   l. T

2.

Core	D
Armature	C
Spring	B
Contacts	A
Coil	E

3.

SPST NO	C
SPST NC	B
SPDT	A

4. C

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER INSTRUCTION.

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ATC ST 3AQR3X020-X
Prepared by Keesler TTC
KEP-GP-17

Technical Training

Electronic Principles (Modular Self-Paced)

Module 17

MICROPHONES AND SPEAKERS

1 July 1975

AIR TRAINING COMMAND

76

Designed For ATC Course Use

ATC Keesler 6-3536

DO NOT USE ON THE JOB

C-E Officer and Space Surveillance Department
Keesler Air Force Base, Mississippi

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KEP-GP-17
1 July 1975

ELECTRONIC PRINCIPLES

MODULE 17

MICROPHONES AND SPEAKERS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

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TITLE	PAGE
Overview	1
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Adjunct Guide	1
Module Self Check	2

OVERVIEW

1. SCOPE: This module describes the basic design of speakers and microphones and explains the operations of each.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. Given a group of statements, select the one that describes the operation of a speaker.

b. Given a group of statements, select the one that describes the operation of a microphone.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY OR TAKE THE MODULE SELF-CHECK. CONSULT YOUR INSTRUCTOR IF YOU REQUIRE ASSISTANCE.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the referenced materials as directed.

Return to this guide and answer the questions.

Check your answers against the answers at the back of this guide.

If you experience any difficulty, contact your instructor.

Supersedes KEP-GP-17, 1 July 1974, which will be used until stock is exhausted.

A. Turn to Student Text, Volume II, and read paragraphs 5-14 through 5-21. Return to this page and answer the following questions.

1. Mark each of the following as true (T) or false (F) concerning loudspeakers and earphones.

_____ a. A loudspeaker converts sound waves to an electrical signal.

_____ b. A loudspeaker converts electrical energy to sound waves.

_____ c. The dynamic loudspeaker is commonly used today.

_____ d. The dynamic speaker is a moving coil speaker.

_____ e. The electromagnetic speaker uses a field coil in place of the voice coil.

_____ f. The speaker is free to move along with the permanent magnet.

_____ g. A PM speaker uses a field coil.

_____ h. The moving coil is the voice coil of a speaker.

_____ i. The voice coil is wound on a cylinder of bakelite or fiber.

_____ j. The spider is attached to the speaker cone and voice coil.

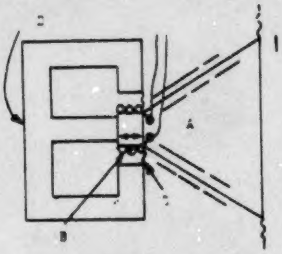
_____ k. In the earphone the voice coil is replaced with coils placed on the pole pieces.

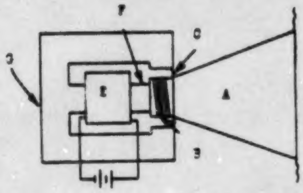
_____ l. The diaphragm in an earphone serves the same function as the cone in the dynamic loudspeaker.

_____ m. The tension on the diaphragm in an earphone varies at an audio rate.

2. Match the parts of the speakers to the list.

a. Cone _____
b. Spider _____
c. Field Coil _____
d. Voice coil _____
e. Permanent Magnet _____
f. Electromagnet _____
g. Soft iron core _____





CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDE.

B. Turn to Student Text, Volume II, and read paragraphs 5-22 through 5-35. Return to this page and answer the following questions.

1. Which of the following are true concerning microphones?

_____ a. All microphones are electroacoustic transducers.

_____ b. Sound waves are converted to electrical energy.

_____ c. A carbon microphone employs carbon granules having a resistance which will change according to the sound waves impressed on the microphone.

______ d. As the carbon granules are compressed by the sound waves the electrical resistance is increased.

______ e. A carbon microphone has a very high frequency response.

______ f. Voice frequencies work very well with carbon microphones.

______ g. A carbon microphone is relatively inexpensive.

2. Which of the following are true concerning the capacitor microphone?

______ a. It is not considered to be an electro-acoustic transducer.

______ b. Sound waves cause a change in capacitance.

______ c. Frequency response is excellent.

______ d. Mechanical shock has no effect on it.

3. Which of the following are true concerning the crystal microphone?

______ a. Uses the photo-electric effect.

______ b. Uses crystals of Rochelle salt or quartz.

______ c. Has excellent frequency response.

______ d. Is not considered to be rugged.

______ e. It does not require an external power source.

4. Which of the following are true concerning the dynamic microphone?

______ a. Makes use of the moving coil principle.

______ b. A dynamic loudspeaker can be used as a microphone.

______ c. The moving coil generates a DC voltage by generator action.

______ d. Many intercommunications sets use this type microphone.

______ e. Needs an external power source.

5. Which of the following are true concerning the velocity-ribbon microphone?

______ a. Amplitude of the output AC depends on the velocity at which the ribbon moves through the magnetic field.

______ b. Operates essentially the same as the dynamic microphone.

______ c. Needs an external power source.

______ d. Uses an electromagnet for the magnetic field.

______ e. Is very directional.

CONFIRM YOUR ANSWERS IN THE BACK OF THIS GUIDE.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

MODULE SELF-CHECK

1. Indicate which are true (T) and false (F) concerning speakers.

______ a. All speakers are electromagnetic devices which convert electrical energy to audio frequencies.

______ b. A speaker converts electrical energy to sound waves.

______ c. An earphone is like a speaker except it does not use an electromagnet, only a horseshoe magnet.

______ d. The diaphragm in an earphone will vibrate at the audio rate to produce the sound waves.

______ e. A permanent-magnet dynamic speaker is called a PM speaker.

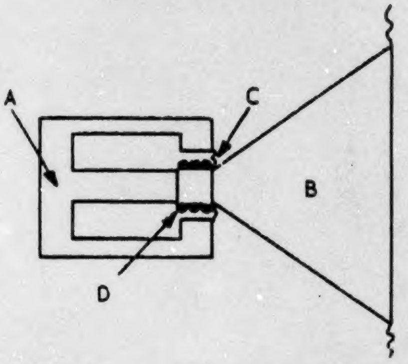
_____ f. Most speakers use a moving coil attached to the cone shaped diaphragm.

_____ g. Alternating current is applied to the field coil in an electromagnetic dynamic speaker.

_____ h. The spider centers the voice coil around the center pole of the main magnet.

2. Match the parts of the speaker to the list.

a. Cone _____
b. Spider _____
c. Magnet _____
d. Voice coil _____



REP4-983

3. Indicate which are true (T) or false (F) concerning microphones.

_____ a. All microphones are electro-acoustic transducers.

_____ b. Microphones take audio frequencies and convert them to sound frequencies.

_____ c. Most microphones use a diaphragm or membrance which vibrates in accordance with frequencies.

_____ d. All microphones do not use the electromagnetic principle.

_____ e. The carbon microphone does use the electromagnetic principle in producing an EMF.

_____ f. The carbon and the capacitor microphone have excellent frequency response.

_____ g. The carbon microphone is good for voice frequencies.

_____ h. The dynamic microphone requires an external power source.

_____ i. Velocity microphones make use of the piezoelectric effect.

_____ j. A dynamic microphone is very much like a dynamic speaker, but not very usable as a speaker.

_____ k. Velocity-ribbon microphones are fairly rugged and reproduce music well.

CONFIRM YOUR ANSWERS IN BACK OF THIS GUIDE.

ANSWERS TO A - ADJUNCT GUIDE

1a. F 1b. T 1c. T 1d. T 1e. F
1f. F 1g. F 1h. T 1i. T 1j. T
1k. T 1l. T 1m. T

2a. A 2b. C 2c. E 2d. B
2e. D 2f. G 2g. F

If you missed ANY questions, review the material before you continue.

ANSWERS TO B - ADJUNCT GUIDE

1. a, b, c, f, g

2. b, c

3. b, c, e

4. a, b, d

5. a, b, e

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK

1. a. F
   b. T
   c. F
   d. T
   e. T
   f. T
   g. F
   h. T

2. a. B
   b. C
   c. A
   d. D

3. a. T
   b. F
   c. T
   d. T
   e. F
   f. F
   g. T
   h. F
   i. F
   j. T
   k. T

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

Prepared by Keesler TTC
KEP-GP-18

Technical Training

Electronic Principles (Modular Self-Paced)

Module 18

METER MOVEMENTS AND CIRCUITS

March 1976

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

ATC Keesler 6-3982

DO NOT USE ON THE JOB

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-18
March 1976

ELECTRONIC PRINCIPLES

MODULE 18

METER MOVEMENTS AND CIRCUITS

This Guidance Package (GP) is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

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Module Self-Check	3
Answers	6

OVERVIEW

1. SCOPE: This module describes the basic theory of meters and the function of their parts.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives:

a. From a group of statements related to meter movements, select the one which describes the function of the:

(1) Permanent magnet.
(2) Moving coil.
(3) Spiral spring.
(4) Pointer.
(5) Scale.

b. From a group of statements related to multimeters, select the one which describes the function of the:

(1) Shunt resistor.
(2) Multiplier resistor.
(3) Ohms zero adjust resistor.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and perference, any or all of the following:

READING MATERIALS:

Digest
Adjunct Guide with Student Text

AUDIO VISUALS:

Television Lessons
LFK-0-30-6 Basic Meter Movements
LFK-0-30-7 Ammeters
LFK-0-30-8 Voltmeters
LFK-0-30-9 Ohmmeters

AT THIS POINT, IF YOU FEEL THAT THROUGH PREVIOUS EXPERIENCE OR TRAINING YOU ARE FAMILIAR WITH THIS SUBJECT, YOU MAY TAKE THE MODULE SELF-CHECK. IF NOT, SELECT ONE OF THE RESOURCES AND BEGIN STUDY. CONSULT YOUR INSTRUCTOR IF YOU NEED ASSISTANCE.

Supersedes KEP-GP-18, November 1975. Previous editions may be used.

ADJUNCT GUIDE

INSTRUCTIONS:

Study the reference materials as directed.

Return to the guide and answer the questions.

Check your answers at the back of this guidance package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to student text, volume II, and read paragraphs 5-36 through 5-43. Return to this page and answer the following questions.

1. Which of the following electric meters does not use the principle of electromagnetism?

____ a. Hot wire ammeter.

____ b. Moving-coil meter.

____ c. Moving-iron meter.

____ d. Dynamometer.

2. Indicate which of the following are true (T) or false (F) concerning the moving-coil meter.

____ a. It is the most popular type.

____ b. The meter movement is referred to as the d'Arsonval movement.

____ c. The stationary magnetic field is produced from an electromagnet.

____ d. Current through the coil produces an electromagnet which reacts with the permanent magnet's lines of force.

____ e. Polarity of the current through the meter is not important.

____ f. Induced current in the aluminum bobbin produces a torque which deflects the needle to the proper reading.

3. Indicate which of the following are true (T) or false (F).

____ a. Most DC moving-coil meters have a linear scale.

____ b. In a linear-scale meter the amount of deflection is directly proportional to the amount of current flow through the coil.

____ c. Meter sensitivity is related indirectly to full-scale deflection (FSD).

____ d. Meter sensitivity can be expressed in milliamps or microamps.

____ e. A meter with an FSD of 50uA is considered more sensitive than one which has an FSD of 50mA.

____ f. It is not possible to use a single meter movement as an ammeter, voltmeter, and ohmmeter.

CONFIRM YOUR ANSWERS.

B. Turn to student text, volume II, and read paragraphs 5-44 through 5-50. Return to this page and answer the following questions.

1. Indicate which of the following are true (T) or false (F).

____ a. The range of all ammeters is determined by the manufacturer and cannot be changed.

____ b. A meter shunt can be used to extend the range of an ammeter.

____ c. The meter shunt causes more current to flow through the meter coil.

____ d. The ammeter is a low resistance device.

____e. Since the ammeter will have a large voltage drop, it should always be connected up in parallel.

____f. When a shunt is used, it will drop the same amount of voltage as the meter coil.

____g. The meter shunt allows current to bypass the meter movement.

CONFIRM YOUR ANSWERS.

C. Turn to student text, volume II, and read paragraphs 5-51 through 5-58. Return to this page and answer the following questions.

1. Indicate which of the following are true (T) or false (F) concerning voltmeters.

____a. They are high resistance devices.

____b. They are usually connected in parallel.

____c. The high resistance offers high current flow.

____d. By adding more resistance in series, more current will flow through the movement.

____e. To exceed the range, more resistance is added in series.

____f. Voltmeter sensitivity can be expressed in ohms per volt.

____g. The higher the resistance per volt, the less sensitive the meter.

CONFIRM YOUR ANSWERS.

D. Turn to student text, volume II, and read paragraphs 5-59 through 5-65. Return to this page and answer the following questions.

1. Indicate which of the following are true (T) or false (F) concerning the ohmmeter.

____a. It does not use the same type basic meter movement as the ammeter and voltmeter.

____b. It needs a source of EMF, such as a dry cell.

____c. It requires a series rheostat to zero the meter.

____d. It requires a fixed series resistor to cause more current to flow.

____e. When zeroing the meter, the test leads are shorted.

____f. It uses an inverse nonlinear scale.

____g. An open resistor, when tested, would indicate no deflection.

____h. A shorted resistor, when tested, would indicate full scale.

____i. The series rheostat allows adjusting for the change in voltage of the ageing dry cell.

2. A multimeter combines the following:

____a. Megameter, fluxmeter, and voltmeter.

____b. Moving-coil meter, voltmeter, ohmmeter, and megameter.

____c. Moving-iron meter, moving-coil meter, and dynamometer.

____d. Voltmeter, ohmmeter, and ammeter.

3. Indicate which of the following are true (T) or false (F).

____a. Connecting a voltmeter across a resistor could affect circuit operation.

____b. It would be best to use a voltmeter with the higher meter sensitivity.

____c. Multimeters can serve as a voltmeter, ohmmeter, or ammeter by proper switch settings.

____d. The multimeter uses three different meter movements.

____e. The battery needs replacement if during the zero adjust the pointer goes past the zero ohms position.

____f. An ohmmeter scale will usually indicate infinity on the right and zero ohms on the left.

CONFIRM YOUR ANSWERS.

MODULE SELF-CHECK

QUESTIONS

1. Indicate if the following are true (T) or false (F) concerning meters.

____a. Three classes of meters use electromagnetism: moving-coil, moving-iron, and the dynamometer.

____b. The moving-coil meter is by far the most common type used today.

____c. A type of moving-coil meter has a permanent magnet.

____d. The moving-iron meter is also called the d'Arsonval movement.

____e. The moving-coil meter has only a few turns of heavy copper wire.

____f. Current through the moving-coil causes a magnetic field which produces a torque on the coil.

____g. Proper polarity must be observed on all moving-coil meter movements.

____h. Meter sensitivity is expressed in milliamps or microamps.

____i. A single meter movement CANNOT be used for an ammeter, voltmeter, and ohmeter.

____j. A meter movement that requires 10uA for full-scale deflection is more sensitive than one which requires 1uA for full-scale deflection.

____k. The ohmmeter scale is a linear-square law scale.

2. Identify the meter parts by matching the proper letter to the name of the part listed in the figure shown below.

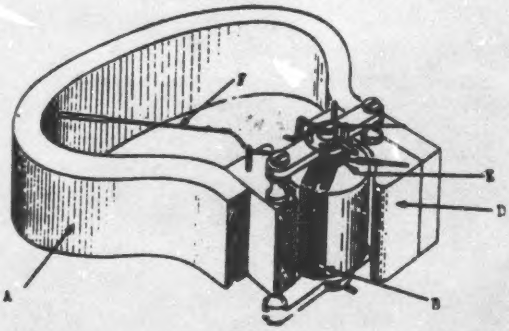
____Pointer

____Permanent magnet

____Spiral spring

____Moving coil

____Pole piece.



3. Match the meter parts to the proper function.

Meter Parts

____a. Permanent magnet.

____b. Moving coil.

____c. Aluminum bobbin.

____d. Pointer.

____e. Pole piece.

____f. Spiral spring.

Function

(1) Indicates actual reading.
(2) Electrical connection and returns pointer to zero.
(3) Causes a permanent magnetic field.
(4) Intensifies the flux.
(5) Sets up electromagnetic field.
(6) Has a current induced in it which causes a torque to oppose oscillations.

4. Which of the following DOES NOT pertain to the moving-coil type meter movement?

____ a. Uses a linear scale for milliamperes and volts.

____ b. Uses a linear scale for ohms.

____ c. Is accurate and rugged.

____ d. Uses a modified d'Arsonval movement.

____ e. Uses a permanent magnet.

____ f. Can be used for measuring current, voltage, or resistance.

5. Which of the following is the most common effect used to detect the presence of a current in moving-coil meters?

____ a. Heating.

____ b. Chemical.

____ c. Electromagnetic.

____ d. Physiological.

____ e. Piezoelectric.

6. In a typical ammeter circuit, shunt resistors are placed:

____ a. In series with the moving coil.

____ b. Across the power source only, not across the meter.

____ c. In parallel with the moving coil.

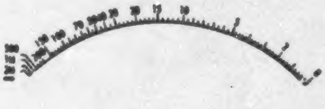
7. Match the scales with the proper terms.

____ a. Square law.

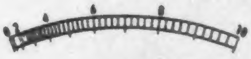
____ b. Linear.

____ c. Nonlinear inverse.

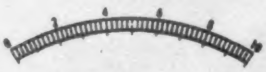
(1)



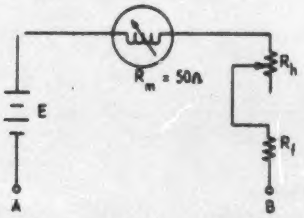
(2)



(3)



Answer questions 8 through 10 in reference to the circuit below:



8. What type of circuit is it?

____

9. What is the purpose of R_h?

____

10. What is the purpose of R_f?

____

11. Indicate which of the following are true (T) or false (F).

____ a. A multimeter uses only one basic meter movement.

____ b. An ohmmeter requires its own power source.

____ c. A voltmeter having 1000 ohms per volt sensitivity is more sensitive than one which has 20k ohms per volt sensitivity.

____ d. The ohmmeter is always connected in parallel to the component being checked.

____ e. An ammeter is always placed in series to find the voltage drop across a resistor.

____ f. A voltmeter is connected in series to find the voltage drop across a resistor.

____ g. The loading effect is important and may cause the voltage reading to be inaccurate.

____ h. To overcome the loading effect, use a voltmeter with a high ohms-per-volt ratio.

____ i. The sensitivity of most meter movements can be changed very easily.

____ j. The average multimeter can be used as an ammeter, voltmeter, frequency meter, dynamometer, and ohmmeter.

CONFIRM YOUR ANSWERS.

ANSWERS TO A - ADJUNCT GUIDE:

1. a
2a. T b. T c. F d. T e. F f. F
3a. T b. T c. F d. T e. T f. F

If you missed ANY questions, review the material before you continue.

ANSWER TO B - ADJUNCT GUIDE:

1a. F b. T c. F d. T e. F f. T
g. T

If you missed ANY questions, review the material before you cntinue.

ANSWERS TO C - ADJUNCT GUIDE:

1a. T b. T c. F d. F e. T f. T
g. F

If you missed ANY questions, review the material before you continue.

ANSWERS TO D - ADJUNCT GUIDE:

1a. F b. T c. T d. F e. T f. T
g. T h. T i. T
2. d
3a. T b. T c. T d. F e. F f. F

If you missed ANY questions, review the material before you continue.

YOU MAY STUDY ANOTHER RESOURCE OR TAKE THE MODULE SELF-CHECK.

ANSWERS TO MODULE SELF-CHECK:

1a. T b. T c. T d. F e. F f. T
g. T h. T i. F j. F k. F

2. F - Pointer; A - Permanent magnet; E - Spiral spring; B - Moving coil; D - Pole piece

3a. (3) b. (5) c. (6) d. (1) e. (4)
f. (2)

4. b 5. c 6. c

7a. (2) b. (3) c. (1)

8. Ohmmeter 9. Zero adjust resistor

10. Current limiting resistor

11a. T b. T c. F d. T e. F
f. F g. T h. T i. F j. F

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.

299

ATC GP 3AQR3X020-X

Prepared by Keesler TTC
KEP-GP-19

Technical Training

Electronic Principles (Modular Self-Paced)

Module 19

MOTORS AND GENERATORS

November 1975

AIR TRAINING COMMAND

7-6

Designed For ATC Course Use

DO NOT USE ON THE JOB

ATC Keesler 6-2369

00308

Radar Principles Branch
Keesler Air Force Base, Mississippi

ATC GP 3AQR3X020-X
KEP-GP-19
November 1975

ELECTRONIC PRINCIPLES (MODULAR SELF-PACED)

MODULE 19

MOTORS AND GENERATORS

This Guidance Package is designed to guide you through this module of the Electronic Principles Course. It contains specific information, including references to other resources you may study, enabling you to satisfy the learning objectives.

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OVERVIEW

1. SCOPE: This module explains the basic theory of operation of motors and generators. Each part is identified and its operation and function is given.

2. OBJECTIVES: Upon completion of this module you should be able to satisfy the following objectives.

a. Given a list of statements about motors and generators, select the one which identifies the purpose of the:

(1) Field coil.
(2) Armature.
(3) Rotor.
(4) Brushes.
(5) Sliprings.
(6) Commutator.
(7) Pole pieces.

b. Given a group of statements, select the ones that describe the operation of a motor.

c. Given a group of statements, select the ones that describe the operation of a generator.

LIST OF RESOURCES

To satisfy the objectives of this module, you may choose, according to your training, experience, and preference, any or all of the following.

READING MATERIALS:

Digest
Adjunct Guide with Student Text II

AUDIOVISUALS:

1. Television Lesson, AC Generators, TVK 30-201
2. Television Lesson, DC Generators, TVK 30-202
3. Television Lesson, DC Motors, TVK 30-703
4. Television Lesson, AC Motors, TVK 30-704

Supersedes KEP-GP-19, 1 April 1975. Use old stock until supply is exhausted.

AT THIS POINT, YOU MAY TAKE THE MODULE SELF-CHECK. IF YOU DECIDE NOT TO TAKE THE MODULE SELF-CHECK, SELECT ONE OF THE RESOURCES AND BEGIN YOUR STUDY. DO NOT HESITATE TO CONSULT YOUR INSTRUCTOR IF YOU HAVE ANY QUESTIONS.

ADJUNCT GUIDE

Study the referenced materials as directed.

Return to this guide and answer the questions.

Confirm your answers at the back of this Guidance Package.

If you experience any difficulty, contact your instructor.

Begin the program.

A. Turn to Student Text, Volume II, and read paragraphs 5-66 through 5-75. Return to this page and answer the following questions concerning generators.

1. Which of the following are true (T) and which are false (F)?

a. A generator converts electrical energy to mechanical energy.

b. Induction is a basic principle involved in generating a current.

c. Relative motion between a conductor and a magnetic field is a requirement of induction.

d. A requirement for induction is that the magnetic field must be produced by an electromagnet.

e. The direction of the current can be determined by applying the left-hand rule.

f. A conductor moving parallel to magnetic lines of force will have maximum voltage induced.

g. A conductor moving at right angles to the magnetic lines of force will have less voltage induced in it than one moving at any other angle.

h. A conductor moving through magnetic lines of force will have more voltage induced in it if the speed is increased.

2. Three requirements for induction are:

a. ______________________________

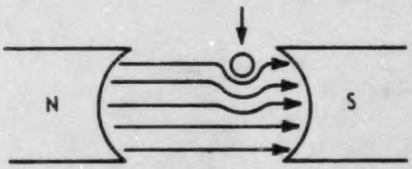
b. ______________________________

c. ______________________________

3. In the figure below, the direction of the induced current would be:

a. Into the page ⊕

b. Out of the page ⊙



REP4-1023

4. Method(s) of increasing the induced voltage is/are to:

a. Decrease the number of conductors.

b. Increase the strength of the magnetic field.

c. Increase the length of time the conductor stays in the magnetic field.

d. Increase the speed of the relative motion.

5. A single loop of wire rotated three complete revolutions within a magnetic field would generate:

a. One complete cycle of AC.

b. Two-thirds of a cycle of AC.

c. Three cycles of AC.

d. Only DC.

CONFIRM YOUR ANSWERS.

B. Turn to Student Text, Volume II, and read paragraphs 5-76 through 5-90. Return to this page and answer the following questions.

1. Indicate which of the following are true (T) and which are false (F) concerning generators:

a. The magnetic field can be produced by either a permanent magnet or by an electromagnet.

b. AC generators use a commutator while DC generators use sliprings.

c. Brushes are used in both AC and DC generators.

d. Both types need a source of mechanical power to turn the armature.

e. The armature will contain many conductors which rotate inside the magnetic field.

f. The core of the armature provides a high reluctance path between the pole pieces.

g. As the conductors rotate they cut the electrostatic lines of force.

h. The EMF induced in the conductors will always be AC when the armature is rotated.

i. The commutator segments provide a means of switching the connections to get DC out.

j. The output of a DC generator is a pulsating DC.

2. Identify the parts of the generator shown by matching the proper letter to the proper term.

____ Armature

____ Brushes

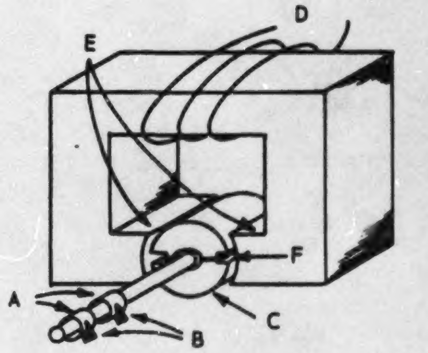
____ Field coil

____ Pole pieces

____ Rotating conductor

____ Sliprings

____ Commutator



REP4-1027

3. Match the parts of a generator to the list of functions or use.

PARTS

____ Armature core

____ Brushes

____ Commutator

____ Field coil

____ Pole pieces

____ Rotating conductor

____ Sliprings

FUNCTION

a. Means of connecting output to load.

b. Provides switching action for DC output.

c. Provides a path for the magnetic field.

d. Provides a means of mounting the rotating conductor.

e. Rotates with the armature and provides the connection to the brushes in an AC generator.

f. Provides the magnetic field.

g. Part in which the induced voltage is produced.

CONFIRM YOUR ANSWERS.

C. Turn to Student Text, Volume II, and read paragraphs 5-91 through 5-101. Return to this page and answer the following questions concerning motors.

1. Indicate which of the following are true (T) and which are false (F).

a. A device which converts electrical energy to mechanical energy.

b. The electrical energy develops an electrostatic field.

c. A mechanical force is exerted by the interaction of magnetic fields.

d. All operate on the same principle.

e. The left-hand rule can be used to determine the direction a current carrying conductor will move.

f. A current carrying conductor which moves in a magnetic field will have another voltage induced in it which is called Counter EMF (CEMF).

g. CEMF flows in the same direction as the applied current.

h. CEMF limits armature current to a safe value.

i. CEMF is in phase with the applied voltage.

j. Total voltage available to send current through the conductor is equal to the applied voltage minus the CEMF.

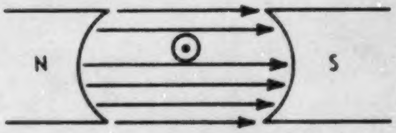
2. Indicate in which direction the current carrying conductor will move under the conditions shown in the illustration.

a. Up

b. Down

c. Left

d. Right



REP4-1025

3. Indicate which of the following are true (T) and which are false (F) concerning motors.

a. Motors can be classified as AC or DC.

b. The turning force of a motor is called torque.

c. The coil is free to rotate in the rotating electrostatic field in a DC motor.

d. The interactions of the magnetic fields develop the torque which causes the shaft to turn.

CONFIRM YOUR ANSWERS.

D. Turn to Student Text, Volume II, and read paragraphs 5-102 through 5-116. Return to this page and answer the following questions concerning AC motors.

1. Indicate which of the following are true (T) and which are false (F).

a. Uses a rotating magnetic field.

b. Only uses single phase AC power.

c. The rotating magnetic field rotates at the synchronous speed.

d. Polyphase AC motors are only connected in the delta configuration.

e. Three phase AC has a 120° electrical separation between the phases.

f. Stator field coils could be wound to produce 60° separation between pole pairs.

CONFIRM YOUR ANSWERS.

MODULE SELF-CHECK

1. Indicate which of the following are true (T) and which are false (F) concerning generators.

a. A generator converts mechanical energy to electrical energy.

b. Any time any conductor moves through a magnetic field so as to CUT these lines an EMF will be induced in that conductor.

c. The direction of the current will be the way the index finger points using the left hand rule.

d. If a conductor moves at a faster rate of speed inside a magnetic field, the magnitude of the induced voltage will be less.

e. Increasing the magnetic field will increase the induced voltage in the conductor if the relative motion stays the same.

f. Increasing the number of conductors will increase the induced voltage.

g. Changing the direction of movement of a conductor in a magnetic field will reverse the direction of the current.

h. Maximum voltage is induced into the conductor as it moves parallel to the magnetic lines.

i. By rotating a single loop of wire within a magnetic field an AC can be generated.

j. An AC generator uses a commutator to make the electrical connections to the armature winding.

k. The DC generator uses sliprings instead of brushes.

l. A commutator will allow the output current of a generator to be only in one direction.

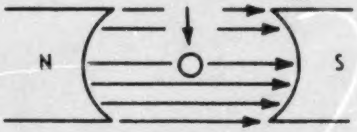
m. The output of a DC generator is a pulsating DC.

n. The output of a two loop DC generator never reaches zero volts as does the single loop generator.

2. Which way is the current flowing as the conductor is moved downward as shown?

a. Out of the page ⊙

b. Into the page ⊕



3. Match each generator component to its purpose.

COMPONENTS

____ Pole pieces

____ Armature core

____ Brushes

____ Sliprings

____ Commutator

____ Field coil

____ Rotor

____ Rotating conductor

PURPOSE

a. Connects rotor winding to brushes in an AC generator.

b. Rotating part on which the rotating conductor is wound.

c. Connects rotor winding to brushes in a DC generator.

d. Provides a low reluctance path for magnetic lines.

e. Provides a low reluctance path between pole pieces.

f. Conductor in which the EMF is induced.

g. Provides the electromagnetic field.

h. Makes an electrical connection to the sliprings or commutator.

4. Indicate if the statement is true (T) or false (F) concerning motors.

a. A motor will change mechanical energy to electrical energy.

b. All motors use the principle of a force exerted between a stationary and a movable magnetic field.

c. Turning force of a motor is called torque.

d. A rotating conductor in a motor will produce a counter EMF.

5. Match each condition with the proper figure of a current carrying conductor.

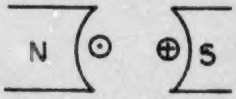
____ No torque

____ CW rotation

____ Medium torque

____ Maximum torque

____ CCW rotation

a


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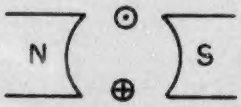
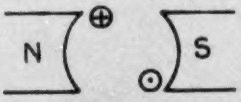


c


CONFIRM YOUR ANSWERS.

ANSWERS TO A:

1. a. F
   - b. T
   - c. T
   - d. F
   - e. T
   - f. F
   - g. F
   - h. T
2. a. conductor
   - b. magnetic field
   - c. relative motion
3. a
4. b, d
5. c

If you missed ANY questions, review the material before you continue.

ANSWERS TO B:

1. a. T
   - b. F
   - c. T
   - d. T
   - e. T
   - f. F
   - g. F
   - h. T
   - i. T
   - j. T
2. C, B, D, E, F, A, none
3. d, a, b, f, c, g, e

If you missed ANY questions, review the material before you continue.

ANSWERS TO C:

1. a. T
   - b. F
   - c. T
   - d. T
   - e. T
   - f. T
   - g. F
   - h. T
   - i. F
   - j. T
2. b
3. a. T
   - b. T
   - c. F
   - d. T

If you missed ANY questions, review the material before you continue.

ANSWERS TO D:

1. a. T
   - b. F
   - c. F
   - d. F
   - e. T
   - f. T

If you missed ANY questions, review the material before you continue.

ANSWERS TO MODULE SELF-CHECK:

1. a. T
   - b. T
   - c. F
   - d. F
   - e. T
   - f. T
   - g. T
   - h. F
   - i. T
   - j. F
   - k. F
   - l. T
   - m. T
   - n. T

2. b

3. d, e, h, a c, g, b, f

4. a. F
   b. T
   c. T
   d. T

5. b, c, c, a, a

HAVE YOU ANSWERED ALL OF THE QUESTIONS CORRECTLY? IF NOT, REVIEW THE MATERIAL OR STUDY ANOTHER RESOURCE UNTIL YOU CAN ANSWER ALL QUESTIONS CORRECTLY. IF YOU HAVE, CONSULT YOUR INSTRUCTOR FOR FURTHER GUIDANCE.